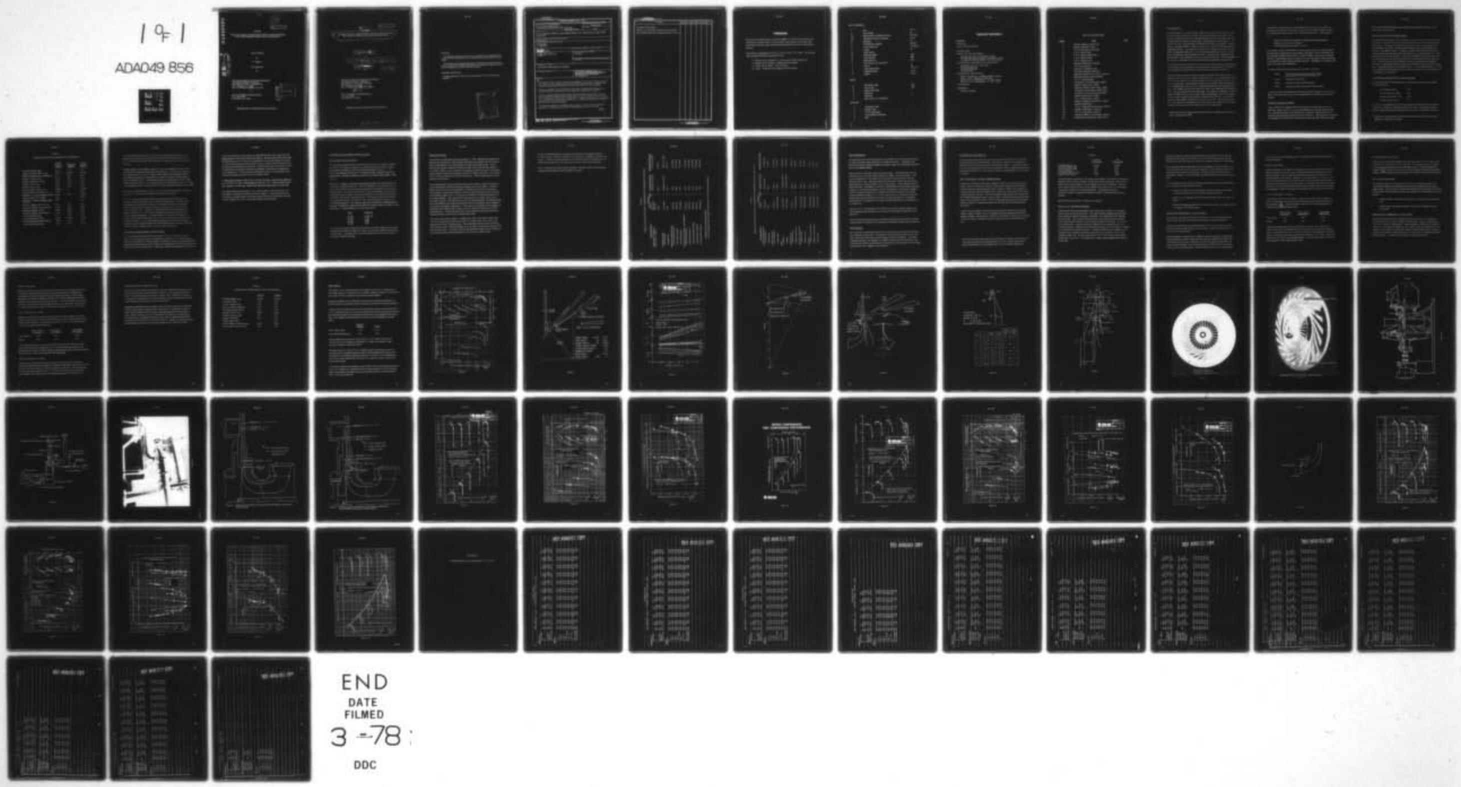
AD-A049 856 SOLAR TURBINES INTERNATIONAL SAN DIEGO CA F/G 13/7
TEST EVALUATION OF STATIONARY AND ROTATING DIFFUSERS FOR A HIGH--ETC(U)
OCT 77 C RODGERS, L BLINMAN DAAG53-76-C-0107

UNCLASSIFIED ER-2602 NL

1 of 1
ADA049 856



END
DATE
FILMED
3-78
DDC

(12)

AD

ER 2602

TEST EVALUATION OF STATIONARY AND ROTATING DIFFUSERS FOR A HIGH PRESSURE RATIO RADIAL COMPRESSOR

FINAL REPORT

by

C. Rodgers

OCTOBER 1977

for

US ARMY MOBILITY EQUIPMENT RESEARCH
AND DEVELOPMENT COMMAND
ELECTRICAL POWER LABORATORY
FT. BELVOIR, VA 22060
REF: CONTRACT DAAG53-76-C-0107

by

SOLAR TURBINES INTERNATIONAL
P.O. BOX 80966
SAN DIEGO, CA 92138

DISTRIBUTION OF THIS REPORT IS UNLIMITED

AD

14 ER-2602

6 TEST EVALUATION OF STATIONARY AND ROTATING DIFFUSERS FOR A HIGH PRESSURE RATIO RADIAL COMPRESSOR.

9 FINAL REP[redacted]T.,

by

10 Colin [redacted]/Rodgers, Lee /Blinman

11 OCT[redacted]77

12 71p.

for

US ARMY MOBILITY EQUIPMENT RESEARCH
AND DEVELOPMENT COMMAND
ELECTRICAL POWER LABORATORY
FT. BELVOIR, VA 22060
REF: CONTRACT DAA[redacted]53-76-C-0107

15

by

SOLAR TURBINES INTERNATIONAL,
P.O. BOX 80966
SAN DIEGO, CA 92138

DISTRIBUTION OF THIS REPORT IS UNLIMITED

326 550

mt.

Disclaimer

The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

The citation of trade names and names of manufacturers in this report is not to be construed as official Government endorsement or approval of commercial products or services referenced herein.

Disposition Instructions

Destroy this report when it is no longer needed. Do not return to the originator.

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Solar Turbines International ✓ An International Harvester Group, San Diego, California 92138	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP N/A

3. REPORT TITLE

Test Evaluation of Stationary and Rotating Diffusers for a High Pressure Ratio Radial Compressor

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report

5. AUTHOR(S) (First name, middle initial, last name)

Colin Rodgers

Lee Blinman

6. REPORT DATE November 1977 Octo	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
8a. CONTRACT OR GRANT NO. DAA[illegible]53-76-C-0107 new b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) ER 2602 ✓ 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	

10. DISTRIBUTION STATEMENT

Distribution of this Report is Unlimited

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY U.S. Army, Mobility Equipment Research and Development Command Electrical Power Laboratory, Ft. Belvoir, VA

13. ABSTRACT

The design of a free rotating vaneless/vaned diffuser (F. R. D.) for a nominal 1.9 pps, high pressure ratio, single stage radial compressor was completed, together with a comparative conventional stationary vaneless/vaned optimum channel diffuser.

Both types of diffuser were subsequently fabricated and individually installed in an existing turbodrive compressor rig for comparative performance evaluation.

At 100% corrected design impeller speed, equal to 62,000 rpm, the peak pressure ratio and adiabatic efficiency for the stationary and F. R. D. systems were 7.91 and 72.6% compared to 7.43 and 70%, respectively. Impeller efficiency was not repeatable and reduced 3.8% at design speed with the F. R. D. installed, probably as a result of different radial clearance settings.

Overall peak vaneless/vaned diffuser static pressure recovery was essentially the same (0.61) at design speed with either the stationary or F. R. D. systems.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Centrifugal Compressor Diffuser, Free Rotating Vs Stationary Compressor, High Pressure Ratio Free Rotating Diffuser (F. R. D.)						

FOREWORD

This work was authorized under Contract DAA●53-76-C-0107 to extend comparative performance evaluation tests on an experimental high pressure ratio single stage centrifugal compressor rig to both conventional stationary and free rotating diffuser systems.

The technical representative of the U.S. Army was Mr. F.D. Jordan. The principal Solar personnel attached to the program were:

- L. Blinman and R. Strassburg - Program and Contract Management
- C. Rodgers and M. Lafferty - Design and Test Analysis
- D. Lucas, and M. Sandlin - Test Evaluation
- W. Brees - Preparation and Editing of the Final Report

LIST OF SYMBOLS

A	Area	sq in
b	Blade Height	in.
Cp	Specific Heat at constant pressure	B.t.u/lb
Cu	Tangential Velocity Component	f.p.s.
D	Diameter	in.
g	Gravitational Constant	ft/sec^2
J	Joules Equivalent	ft lb/B.t.u.
L	Length	in.
M	Mach Number	-
N	Rotational Speed	rpm
P	Total pressure	psia
p	Static pressure	psia
q	Work factor = $g\ J\ Cp\ \Delta T/U_2^{\ 2}$	-
r	Radius	in.
T	Total Temperature	°R or °F
U	Tangential Speed	f.p.s.
W	Airflow	p.p.s.

GREEK

α	Streamline Angle	deg.
β	Blade Angle	deg.
γ	Specific Heat Ratio	-
Δ	Difference	-
η	Efficiency	%
λ	Speed ratio (F.R.D/Impeller	-

Subscripts

1	Compressor Inlet
2	Impeller Exit
3	F.R.D. Discharge
4	Vaned Diffuser Discharge
E	Exit

TABLE OF CONTENTS

SUMMARY

FOREWORD

LIST OF ILLUSTRATIONS

INTRODUCTION

DESIGN ANALYSIS AND DESIGN

Stationary Vaneless/Vaned Diffuser Design
Free Rotating Vaneless Diffuser Aerodynamic Design
Free Rotating Vaneless Diffuser Structural Design

EXPERIMENTAL EQUIPMENT AND PROCEDURE

Fabrication and F. R. D. Spin Test
Turbodrive Test Rig
Test Rig Installation
Instrumentation

DISCUSSION OF TEST RESULTS

Build 7 Performance - Stationary Diffuser System
Build 8 F. R. D. Mechanical Shakedown
Build 9 F. R. D. Performance - 12 F. R. D. Struts
Build 10 F. R. D. Performance - 6 F. R. D. Struts

CONCLUSIONS

APPENDIX A

Reduced Test Data

LIST OF ILLUSTRATIONS

Figure	Title	Page
1	Baseline Impeller Performance	
2	Stationary Diffuser Design	
3	F.R.D. Estimated Performance	
4	F.R.D. Blade Design	
5	F.R.D. Design Configuration	
6	F.R.D. Stress Results	
7	F.R.D. Detail Layout	
8	Stationary Diffuser and Impeller	
9	F.R.D. and Impeller	
10	Turbodrive Compressor Rig	
11	Test Cell Installation Schematic	
12	Installed Turbodrive Rig (Before insulation)	
13	Stationary Diffuser Instrumentation	
14	F.R.D. Instrumentation	
15	Compressor Test Performance, Build 7	
16	Impeller Performance, Build 7	
17	Stationary Diffuser Performance, Build 7	
18	Comparative Performance, Build 3 and 7	
19	Compressor Test Performance, Build 9	
20	Impeller Performance, Build 9	
21	F.R.D. Performance, Build 9	
22	Stationary Diffuser Performance, Build 9	
23	Impeller Modification	
24	F.R.D. Compressor Performance, Build 10	
25	Impeller Performance, Build 10	
26	F.R.D. Performance, Build 10	
27	Stationary Diffuser Performance, Build 10	
28	Performance Comparison, Build 7 and 9	

INTRODUCTION

In 1971 the (then) U.S. ARMY Mobility Equipment Research and Development Center (MERDC) issued a contract to the Solar Division of International Harvester to perform the mechanical design of an experimental high pressure ratio single-stage centrifugal compressor test rig incorporating a rotating vaneless/vaned diffuser. The test rig was to be a self-contained unit including the compressor impeller, rotating diffuser, stationary diffuser, shafts, bearings, seals, shrouds, instrumentation and supporting structure. The compressor rig was to be designed, based upon Army-furnished aerodynamic design data. A test evaluation program plan was also to be prepared, identifying the instrumentation systems, mechanical and aerodynamic tests, test objectives, and analytical procedures for the data reduction. Upon design approval, all major rig components were to be manufactured and assembled ready for test.

In 1972 the contract was extended to cover test evaluation of compressor performance with the first rotating vaneless/vaned diffuser design. Subsequently, two additional rotating diffuser configurations were fabricated and performance evaluated.

Reference [1] shows the best overall performance attained at 100% design speed was a pressure ratio of 7.7 with an adiabatic efficiency of 72.3% at a rotating diffuser speed ratio of 0.30, compared to the design pressure ratio and efficiency goals of 9.0 and 84.5%, respectively. Peak impeller efficiency was calculated, using a windage loss of 3.7% at design speed, and was 85.5%, eight percentage points lower than the design goal. The rotating vaneless/vaned diffuser pressure drop coefficient $\Delta P/P$ (inlet) was 0.24, some 40% greater than the design intent. Nevertheless, installation of rotating diffuser of Build 2 did increase overall compressor efficiency by up to 5% compared to the stationary vaneless/vaned diffuser configuration of Build 1B. The maximum stationary vaned diffuser static pressure recovery was 0.64. The most notable feature of the compressor performance was the broad flow ratio range of 1.25 obtained between choke and surge with the diffuser rotating at design speed.

[1] Design and Test of an Experimental Rotating Diffuser Centrifugal Compressor Test Rig: C. Rodgers SAE 760927

The objective of this program was the continuation of previous work to enable an evaluation and comparison of test performances of three candidate diffuser systems for a single stage, high pressure ratio, centrifugal compressor. These systems are:

Rotating Vaneless/Vaned Diffuser (configuration previously tested)
Stationary Vaneless/Vaned Diffuser
Free Rotating Vaneless Diffuser (F. R. D.)

The rotating vaneless/vaned diffuser previously tested presented a difficult installation problem in an actual gas turbine engine, in that power had to be extracted from it, requiring an additional gear train to couple the diffuser to the engine mainshaft. The free rotating diffuser does not require such a gearing system, and thus presents a somewhat less complex engine installation problem. Installation of a stationary diffuser is of course the least difficult.

The work of this program was divided into four tasks, covering:

Task 1	Perform design analysis and complete design drawings for the test diffuser and test rig.
Task 2	Fabricate test hardware
Task 3	Set up the rig and conduct the testing
Task 4	Analyze the results and prepare the final report

A program plan was subsequently completed and budgets assigned to each of the four tasks. The budget data was used for the preparation of the Performance and Cost Reports.

DESIGN ANALYSIS AND DESIGN

Task 1 called for the design analysis and completion of design drawings for the stationary diffuser and F.R.D., for incorporation into the existing turbodrive test rig. Aerodynamic design of the diffusers was conducted, using the baseline test impeller performance characteristics shown on Figure 1. This impeller was previously developed under MERADCOM contract and was of moderately low specific speed

with 28 radial blades exhibiting a peak impeller adiabatic efficiency of 85% at the design speed of 62,000 rpm.

Stationary Vaneless/Vaned Diffuser Design

The matching of the impeller and vaned diffuser at high pressure ratios is of critical importance and is affected by the vaneless space diameter ratio and the vaned diffuser throat area. Of secondary importance are the throat aspect ratio and downstream channel diffuser geometry, which principally influence the overall static pressure recovery of the diffuser system. Computer matching studies showed that the best compromise between operating range and efficiency was a diameter ratio of 1.18 with a throat area of 1.04 square inches. Under these conditions, the diffuser inlet Mach No. was subsonic at 0.83 and the estimated flow ratio between choke and surge was 1.09. The throat aspect ratio and diffuser channel were optimized for maximum recovery, resulting in the stationary vaneless/vaned diffuser geometry shown in Figure 2. Estimated performance is listed in Table I. At a corrected airflow of 1.83 pps it was anticipated that this geometry should attain a pressure ratio of 7.9 with an overall efficiency of 71.3 percent.

Free Rotating Vaneless Diffuser Aerodynamic Design

Free Rotating Diffuser design studies were conducted using the following impeller exit flow conditions:

Exit Absolute Mach No.	1.25
Exit Absolute Flow Angle	78.6°
Diffuser width/radius ratio	0.044
Diffuser diameter ratio	1.3

The F.R.D. estimated performance was calculated, using the procedure outlined in Reference [2], assuming a coefficient of friction of 0.005, and is plotted against an abcissa of inlet Mach number with speed ratio U2/CU2 as a parameter in Figure 3.

[2] Analytical, Experimental and Mechanical Evaluation of Free Rotating Vaneless Diffusers; C. Rodgers; AD 744475

TABLE 1

ESTIMATED DIFFUSER PERFORMANCE COMPARISONS

	Build 3 Rotating Diffuser	Stationary Diffuser	Free Rotating Diffuser
Corrected Airflow, pps	1.68	1.83	1.93
Impeller Rotational Speed, rpm	62,000	62,000	62,000
Impeller Efficiency (inc. windage), %	83.3	83.6	83.6
Impeller Pressure Ratio	10.5	10.2	10.2
Impeller Temperature Ratio	1.140	1.116	1.116
Impeller Work Factor	0.95	0.93	0.93
Impeller Tip Mach No.	1.27	1.25	1.25
Rotating Diffuser Speed, rpm	18,600	0	28,000
Rotating Diffuser Rel Mach. No.	0.89		0.86
Rotating (or Vaneless) Diffuser, $\Delta P/P$	0.23	0.15	0.078
Rotating Diffuser Work Ratio	1.05		1.003
Rotating (or Vaneless) Diffuser Exit, Dia. in.	11.2		9.4
Stationary Diffuser Entry Dia. in.	11.6	8.5	10.2
Stationary Diffuser Entry Mach No.	0.56	0.83	0.79
Stationary Diffuser, $\Delta P/P$	0.045	0.09	0.07
Stationary Diffuser Exit Mach No.	0.27	0.23	0.22
Overall Pressure Ratio	7.7	7.9	8.7
Overall Temperature Ratio	1.083	1.116	1.111
Overall Efficiency (Total-Total), %	72.3	71.3	76.1
Flow Range (Choke/Surge)	1.25	1.09	1.15

At an entry absolute Mach No. of 1.25 and free rotating speed ratio of 0.45, the diffuser total pressure loss coefficient, as a function of the inlet dynamic head, is 0.14. The equivalent pressure loss coefficient as a function of the inlet total pressure is 0.078.

Matching studies were completed, using a F.R.D. loss coefficient, $\Delta P/P$, of 0.078 with the baseline impeller performance characteristics. A downstream stationary vaned diffuser throat area of 1.04 square inches (equal to the stationary vaneless/vaned diffuser system) was determined to be optimum, using the existing diffuser vanes from Builds 5 and 6. Estimated performance for the proposed F.R.D. configuration is listed in Table I. It is estimated that an overall pressure ratio of 8.7, with a corresponding adiabatic efficiency of 76.1%, could be attained with the F.R.D. design.

Main core streamline paths for the F. R. D. at the design inlet conditions with speed ratios of 0, 0.4 and 0.5 were computed and are shown on Figure 4.

The F. R. D. front shroud support blades would ideally be positioned along such calculated relative streamline paths for the desired speed ratio. However, three dimensional flows will probably result in an incidence variation onto the blades, thereby causing different sections of the blade to operate away from the desired "neutral" driving mode. Additionally, the prediction of the free running speed is limited to accuracy ± 10%, as prasitic drag effects from the bearings and brake are not precisely established. For these reasons, it was decided to position a simple structural blade shape between the 0.4 and 0.5 speed ratio streamline paths as shown on Figure 4. For aerodynamic drag reasons, it was desired to employ a minimum number of support blades, thus a finite element stress model was generated to study the effect of blade number on F. R. D. structural integrity.

Free Rotating Vaneless Diffuser Structural Design

A two-dimensional finite element stress model of the F. R. D. geometry, shown in Figure 5, was generated and stress computations completed at a free rotating speed ratio of 0.45 (27,900 rpm). Stress results are tabulated on Figure 6 and indicate that the maximum blade stress occurs in the vicinity of the leading edge and front shroud, increasing from 32.5 to 42.5 thousand p.s.i. (KSI) with a reduction in blade number from 12 to 6.

F. R. D. growths with 12 and 6 vanes are essentially the same with a maximum axial displacement of 0.085 inches at 500°F near the tip. Design radial growth at the double lip labyrinth seal was .047 inches, and assessed to be more than adequate to provide a "rub-in" seal condition with appropriate choice of a smaller cold clearance between the labyrinth and abradable seal material. Venting of the forward cavity of the F. R. D. to ambient will be provided to prevent the possibility of labyrinth seal leakage back to the impeller tip. Vent size should be sufficient to permit a 4% flow bypass which could be accomplished with six 0.15 inch. diameter holes.

A critical speed analysis of the F.R.D. assembly was made, using bearing stiffnesses of 0.5×10^6 lb. in. with a rotating diffuser weight of 4.2 lb. Only one critical speed was computed at 41,682 rpm, which is well beyond the design speed of 28,000 rpm.

The detail design geometry of the F. R. D. and its relative "cold" axial stack-up to the impeller and stationary diffuser is shown in Figure 7. Critical features in the cold stack-up measurements are the axial clearances between the impeller and front shroud, impeller and F. R. D., and radial labyrinth seal clearance.

EXPERIMENTAL EQUIPMENT AND PROCEDURE

Fabrication and F. R. D. Spin Test

Two new major components fabricated for the program were the stationary diffuser and F. R. D. The stationary diffuser was integrally machined by contour milling from stainless steel plate, and is shown with the impeller in Figure 8. The F.R.D. was integrally machined from a Titanium forging, originally with twelve neutral struts, and finish-machined, matched to an existing rotating diffuser shaft and seal.

The F.R.D., impeller, and downstream stationary diffuser are shown in Figure 9 to portray the component flowpath. Prior to installation in the turbodrive rig, the F. R. D. was installed on its actual rotor assembly and dynamically balanced prior to the spin test. It was then removed from the rotor and installed in a spin fixture containing inductive proximity probe instrumentation to measure axial deflection at the diffuser outer flange during spin testing. The diffuser was slowly accelerated in an evacuated chamber to 30,000 rpm, with pauses at 5000 rpm increments, to record flange deflection. The maximum speed was maintained for approximately 30 seconds. The diffuser satisfactorily completed the spin test with no evidence of structural failure. Flange deflection vs. rpm is shown below:

RPM	Deflection
15,000	0.006 inch
20,000	0.013
25,000	0.022
28,000	0.029
30,000	0.034

At 28,000 rpm, the axial deflection at the tip was 0.029 inch compared to the design estimate of 0.044 inch (see Figure 6). There was less than 0.002 inch deflection up to 10,000 rpm. A comparison of critical dimensions before and after the spin test revealed no significant changes.

Turbodrive Test Rig

The turbodrive configuration is shown in Figure 10. This configuration comprises two separate aerodynamically coupled rotating assemblies; the impeller with its drive turbine, and the diffuser rotor, each with its own shaft and bearing system. Each of these bearing systems consists of preloaded angular contact ball bearings mounted in a capsule, which in turn is mounted in its respective support housing. The impeller/turbine capsule mounts three bearings, including a matched tandem pair at the impeller end to carry the combined axial thrust of both rotors. Both bearings systems employ pressure jet lubrication.

The rotating diffuser is positioned with respect to the impeller through the fabricated scroll assembly with shimming adjustment possible at the scroll flange. Impeller to shroud axial clearance can be established at assembly by shimming at the bearing housing flange. The shroud itself has a bonded abradable coating to minimize damage from potential impeller rubs. A stationary vaned diffuser is installed downstream of the rotating diffuser, and is mounted with clamping screws to insure that no gap is left at the vane ends. The diffuser rotor has a two-stage staggered, overhung labyrinth seal at the diffuser entry to prevent discharge to inlet recirculation, and is designed to rub in during operating at rated speed. A five-step seal is installed at the periphery of the diffuser rotor support shaft to reduce direct air leakage to ambient, and control axial end thrust. A small three-step seal is used adjacent to the bearing assembly to minimize the lube oil loss from the bearing drain cavity.

The drive turbine section employs a modified Solar Titan radial inflow turbine rotor and nozzle capable of providing 400 hp output at a pressure ratio of 5.5 and an inlet temperature of 1300°F at design speed. The multi-stage labyrinth seal at the turbine hub has provision for buffering with shop air as necessary to prevent overheating of the lube oil drain cavity. A ten start viscoseal with knurling of shaft surface is installed at the compressor hub to prevent migration of lube oil into the impeller inlet.

Impeller and rotating diffuser speeds were sensed by electromagnetic induction proximity probes. Externally mounted accelerometers are installed on each bearing housing. Protection against malfunctions is provided by automatic shutdown devices sensing rotor speeds, low oil pressure and excessive turbine inlet temperature

Table 2 contains a list of parameters monitored. Figures 13 and 14 show the instrumentation in the impeller shroud and diffuser sections.

TABLE 2

MERDC ROTATING DIFFUSER COMPRESSOR RIG INSTRUMENTATION LIST

MEASUREMENT	SENSOR TYPE	SENSOR QTY	READOUT DEVICE	ESTIMATED RANGE
Compressor air flowrate (2.99 in. dia. venturi)	Static pressure tap	3	Manometer & DAS**	-75 to 0 in. H_20
	RTD*	1	DAS	40-90°F
Compressor inlet:				
Total pressure	Kiel probe	3	Manometer & DAS	-12 to 0 in. H_20
Temperature	RTD	3	DAS	45-85°F
Stationary vaned diff (only):				
Throat static pressure	Wall tap	2	DAS	15-70 psia
Exit static pressure	Wall tap	3	DAS	17-75 psia
Exit total pressure	Kiel probe	3	DAS	17-80 psia
Rotating vaneless/dnstm vaned diffuser:				
Seal static pressure	Wall tap	2	DAS	15-85 psia
Exit static pressure	Wall tap	6	DAS	15-85 psia
Vane throat static pressure	Wall tap	2	DAS	15-85 psia
Vane exit static pressure	Wall tap	3	DAS	15-90 psia
Vane exit total pressure	Kiel probe	3	DAS	15-95 psia

* Resistance Temperature Detector

** Data Acquisition System pressure signal source is a 0-150 psia transducer

TABLE 2

MERDC ROTATING DIFFUSER COMPRESSOR RIG INSTRUMENTATION LIST (Cont)

MEASUREMENT	SENSOR TYPE	SENSOR QTY	READOUT DEVICE	ESTIMATED RANGE
Compressor discharge:				
Total pressure	Kiel probe	1	DAS and gage	15-100 psia
Temperature	RTD	3	DAS	70-650°F
Turbine inlet duct:				
Static pressure	Wall tap	1	Gauge	0-80 psig
Temperature	Thermocouple	1	Meter	70-1300°F
Speed:				
Impeller	Prox. Probe	1	Frequency meter	0-14750 Hz
Diffuser	Mag Pickup	1	Frequency meter	0-1900 Hz
Lubrication Oil·				
Supply pressure	Wall tap	1	Gauge	0-45 psig
Supply temperature	Thermocouple	1	Meter	60-90°F
Discharge temperature:				
Impeller rotor	Thermocouple	1	Meter	70-250°F
Diffuser rotor	Thermocouple	1	Meter	70-210°F
Vibration:				
Impeller rotor housing	Accelerometer	1	Meter	0-15 G
Diffuser rotor housing	Accelerometer	1	Meter	0-25 G
Dynamometer	Accelerometer	1	Meter	0-3 G

Test Rig Installation

The turbodrive was specifically designed for installation into an existing facility used for Solar's advanced radial compressor development program. Constraints were observed during the design and planning activities, in part, by matching the rig dimensions to the existing facility.

Figure 11 shows a schematic layout of the test facility. Plant compressed air was heated with an in-line natural gas combustor for supply to the drive turbine. Flow rate and temperature at the turbine were modulated by manual control from the adjacent control room. Automatic speed governing was available, but not required, since the plant air supply pressure was extremely stable. A self-contained lube oil system was used, consisting of a reservoir, electrically driven rotor pump, pressure regulator, oil/water heat exchanger, and two accumulators to maintain oil supply in event of an electrical power loss. Compressor inlet air was drawn from outside ambient conditions through a 3.0 or 4.5 in. venturi to the cell through an inlet muff shielded from the hot turbine drive section to prevent heat pick-up. Compressor back pressure was regulated by a remotely controlled butterfly valve downstream of the orifice run.

When the F. R. D. was installed it was allowed to rotate free without coupling to the Kahn high speed water dynometer used in previous performance calibrations, (see Figure 12).

Protection against malfunctions was provided by automatic shutdown devices sensing impeller speed, vibrations, low oil pressure and excessive turbine inlet temperature.

Instrumentation

Data required for aerodynamic performance evaluation was recorded by an automatic data acquisition system (DAS). This system records multiple channels of non-transient, linearized temperatures and strain gage transducer pressures. The output, in engineering units, was displayed on a digital voltmeter and on printed paper tape. Performance evaluation measurements not compatible with this system were recorded manually from their respective visual displays.

DISCUSSION OF TEST RESULTS

The test program for performance evaluation of the stationary and F. R. D. diffuser configurations covered the four builds. The optimum stationary vaned diffuser was installed for the first build of the new series of tests, Build 7. A mechanical shake-down run was conducted with the F. R. D. installed on Build 8, followed by performance calibrations with first 12 F. R. D. struts on Build 9 and subsequently 6 F. R. D. struts on Build 10.

Build 7 Performance - Stationary Diffuser System

Performance calibration tests were completed on Build 7 of the experimental compressor with the rotating vaned diffuser replaced by the stationary vaned diffuser. Overall compressor performance for Build 7 is shown on Figure 15 and indicates a maximum pressure ratio and efficiency of 7.9 and 72.6%* near surge at 100% design corrected speed 62,000 rpm. This was the highest stage pressure ratio attained and the subsequent intentional surge was quite violent, resulting in some permanent deformation of the compressor scroll. Table 3 compares predicted performance with the stationary diffuser to actual test performance at design speed, showing excellent agreement.

Figure 16 shows impeller performance data points superimposed on the baseline impeller map from Builds 3 and 4, indicating essentially unchanged performance. Stationary diffuser static pressure recoveries are presented on Figure 17, revealing a maximum recovery coefficient across the vaneless space and vaned diffuser of 0.63.

* Total-total efficiency based upon calculated diffuser exit total pressure from measured static pressure and continuity, using $\gamma = 1.395$. Using measured total pressure the pressure ratio and efficiency were 8.18 and 74% respectively.

TABLE 3

	Predicted Performance	Test Performance
Rotational Speed, rpm	62,000	62,000
Corrected Airflow, pps	1.83	1.86
Overall Pressure Ratio	7.9	7.91
Overall Efficiency	71.3	72.6
Flow Range (Choke/Surge)	1.09	1.06
Impeller Work Factor	0.93	0.918

The performance comparison of the rotating vaned diffuser from Build 3 and stationary diffuser of Build 7 shown on Figure 18 illustrates the substantial flow range improvement with the rotating diffuser, but with slightly lower peak efficiencies. However, Build 6 tests demonstrated that rotating diffuser seal leakage at 95% corrected speed accounted for almost 2% loss in peak efficiency. Had leakage losses not occurred on Build 3, comparable efficiencies to Build 7 would probably have been attained.

Reduced test data for Build 7 is attached in Appendix I.

Build 8 F. R. D. Mechanical Shakedown

Following the violent surge incident at 100% design speed on Build 7, a substantial amount of rig rework was necessary. The rework involved replacement of the bearings, shafts and impeller with spare components, and modification of the distorted forward casing. The abradable shroud aluminum epoxy coating was also replaced with a nickel graphite coating to provide higher temperature durability. The F. R. D. was installed plus a downstream stationary diffuser with the design throat area of 1.04 square inches. Impeller cold shroud axial clearance was 0.033 inches, compared to 0.024 inches on the previous Build 7. Mechanical check-out was completed to 45% design speed and indicated satisfactory operation of the rig and the F. R. D. in the uncoupled brake mode. The free speed ratio of the F. R. D. to shaft of the impeller varied from 0.34 to 0.37. The maximum free rotation speed attained during test was 23,160 rpm.

Performance checks made during the mechanical checkout of the F.R.D. system indicated that the impeller performance was some 5% in efficiency lower than the established baseline efficiency level and that the stationary diffuser was mismatched.

Post-mechanical checkout inspection of the rig components showed no evidence of a F. R. D. labyrinth seal rub-in condition as intended, or rub-in of the impeller to the abradable nickel graphite shroud coating. The nickel graphite coating was also substantially rougher in surface finish than previously experienced with the aluminum epoxy.

As a consequence of these results the following modifications were recommended for F. R. D. performance calibrations on Build 8.

- Replace abradable coating with aluminum epoxy material and set impeller cold shroud axial clearance comparable to the gap of Build 7.
- Reduce F.R.D. labyrinth seal radial clearance from 0.025, to 0.012-0.017 inches.
- Increase the stationary diffuser throat area from 1.04 to 1.25 square inches by re-stagger of the existing vanes.

Build 9 F. R. D. Performance - 12 F. R. D. Struts

The measured cold impeller shroud axial clearance was set at 0. 020 inch and the inducer radial clearance was measured, varying from 0. 008 to 0. 022 inch.

Performance calibrations were conducted with the F. R. D. unrestrained at 55, 70, 80, 90, 95 and 100% design impeller corrected speed. Surge was determined at 55, 70, 80 and 100% design speed.

Overall compressor performance for Build 9 is shown on Figure 19, and indicates improved efficiency and flow range up to 90% speed as compared with Build 7 and 8, followed by a performance reduction at 95 and 100% speed precipitated by premature impeller choking. Peak overall efficiency attained was 75% at a pressure ratio of 5. 96 at 90% design speed. Maximum pressure ratio at 100% design speed

was 7.43 with an overall efficiency of 70%. Component performances are discussed in detail as follows:

Impeller Performance

Impeller performance for Build 9 is compared to the baseline impeller performance (Reference Builds 3 and 4) on Figure 20 and indicates better performance up to 90% design speed where after evidence of premature choking occurs compared to the baseline impeller flow capacity. Reasons for this choking effect are not clear, apart from the eccentric inducer radial clearance and a concurrent relatively large inlet temperature spread (up to 14°F) at 100% speed. The impeller hub viscoseal clearance varied from 0.002 to 0.007 inch and may have been leaking hot oil fumes to the inlet. It was planned to reduce the clearance to the design value of 0.002 on the next build.

F. R. D. Performance - 12 Struts

Performance of the F. R. D. is shown on Figure 21 in terms of static pressure recovery, total pressure loss ratio and free rotating speed ratio versus impeller tip flow function, $\frac{W\sqrt{T2}}{P2}$. Test performance of the F.R.D. at 100% design speed is compared to design performance below.

	Static Pressure Recovery	Total Pressure Loss Ratio	Free Rotating Speed Ratio
Test, Build 9	0.32	0.32	0.385
Design	0.32	0.14	0.45

Although the design static pressure recovery was attained, total pressure loss ratio (as a fraction of the inlet dynamic head) was still more than double the design intent. Strip down of the F. R. D. showed no evidence of seal rubbing at the labyrinth tips even though cold radial clearance had been reduced to 0.013 inches. Mechanical operation of the F. R. D. was quite satisfactory, a maximum free speed of 24300 rpm being obtained at 100% design impeller speed.

Stationary Diffuser Performance

Performance of the stationary diffuser with and without the F.R.D. for Build 9 with its throat area increased to 1.26 sq. inches (by vane restagger) is shown on Figure 22 showing comparable performances with builds 7 and 8. Maximum choked flow capacity $\frac{W\sqrt{T2}}{P2}$ increased from 0.485 to 0.555 and should have matched the impeller slightly below its choking limit had not premature impeller choking been experienced.

Recommended Modifications

The relatively high total pressure loss of the F.R.D. and slightly reduced free rotating speed suggested that additional loss may be occurring across the neutral support vanes. It was therefore recommended that half the neutral vanes be removed. In an attempt to delay premature choking of the impeller two modifications were incorporated.

- Reduce impeller shaft viscoseal clearance to a uniform gap of 0.002-0.003 inch.
- Modify inducer leading edge as shown on Figure 23 to slightly increase choked flow.

Build 10 F.R.D. Performance - 6 F.R.D. Struts

Performance calibrations were conducted with the six strut F.R.D. installed at 55,68.4,79.0,86,92, and 99.6% design corrected speed. Surge was determined at 55,68,79.0, and 99.6% design speed. Overall compressor performance is shown on Figure 24 and indicated essentially the same pressure ratio and efficiency levels as Build 9 but with significant shifts in the maximum choked diffuser flows. Maximum pressure ratio at 99.6% design speed was 7.3 at surge with a corresponding adiabatic efficiency of 69%. Component performances are discussed as follows:

Impeller Performance

Impeller performance for Build 10 is compared to the baseline impeller performance on Figure 25, and as Build 9 indicates, reduced performance near design speed. Examination of the inlet temperature spread showed that smaller viscoseal radial clearance did reduce the variation to less than 4°F at 99.6% design speed, but peak impeller at this maximum test speed was only 81%. Since the impeller axial clearance was within requirements reduced impeller performance at high speed may have been the result of the eccentric inducer radial clearance varying from .008 to .022 inch.

F. R. D. Performance - 6 Struts

Performance of the F. R. D. with six neutral struts is shown on Figure 26 in terms of static pressure recovery, total pressure loss ratio, and free rotating speed versus impeller tip flow function. Test performance of the F. R. D. at 99.6% design speed is compared to design predictions below.

	Static Pressure Recovery	Total Pressure Loss Ratio	Free Rotating Speed Ratio
Test, Build 10	0.29	0.35	0.315
Design	0.32	0.14	0.45

Total pressure loss ratio was more than double the design intent and free rotating speed ratio with six vanes dropped to 0.315. Post-test strip-down of the F.R.D. still showed no evidence of seal rubbing at the labyrinth tips, thus it must be concluded that some F.R.D. flow recirculation was still taking place.

Stationary Diffuser Performance

Performance of the stationary diffuser with and without the F. R. D. is shown on Figure 27, indicating that its choked flow capacity had apparently increased from 0.55 on Build 9 to 0.62 on Build 10 without any change in throat area. This would amount to a throat blockage difference of 12%. The peak static pressure recovery of the vaned diffuser near design speed was essentially unchanged at the order of 0.65.

Performance Summary Builds 7, 9 and 10

Analysis of the test results for Builds 7, 9 and 10 of the MERADCOM compressor rig reveals that only Build 7 with the stationary diffuser met the design performance goals. Overall compressor performance with the F. R. D. installed was reduced as a consequence of the inability to repeat the baseline impeller performance level and to obtain dynamic closure of the F. R. D. labyrinth seal.

Comparative test performances of Build 7 and 9 are shown in Figure 28, indicating that the overall compressor performance with the F.R.D. installed was better in terms of peak efficiency and flow range except approaching and at design speed, where impeller performance was not repeatable (with different radial clearances) from test-to-test, resulting in the peak pressure ratio and efficiency falling from 7.91 and 72.6% on Build 7 to 7.43 and 70% on Build 9. Maximum overall and component performances for Build 7 and 9 at 100% design speed are listed on Table 4.

TABLE 4

COMPARATIVE DESIGN SPEED TEST PERFORMANCES

	BUILD 7	BUILD 9
Rotational Speed, rpm	62,000	62,000
Corrected Airflow	1.86	1.93
Overall Pressure Ratio	7.91	7.43
Overall Adiabatic Efficiency	72.6	70.0
Flow Range (Choke/Surge)	1.06	1.035
Impeller Work Factor	0.918	0.913
Impeller Pressure Ratio	10.1	9.25
Impeller Efficiency	84.1	80.3
Diffuser Speed Ratio	-	0.39
Overall Diffuser Static Recovery	0.628	0.607
Vaned Diffuser Exit Mach No.	0.28	0.28

CONCLUSIONS

The design of a free rotating vaneless/vaned diffuser (F. R. D.) for a high pressure ratio single stage radial compressor was completed together with that of a comparative conventional stationary vaneless/vaned optimum channel diffuser.

Both types of diffuser were subsequently fabricated and individually installed in an existing turbodrive compressor rig for comparative performance evaluation purposes.

Analysis of the test results showed that the overall compressor performance with the F. R. D. installed was better in terms of peak efficiency and flow range except approaching and at design speed, where impeller performance was not repeatable from test-to-test. This resulted in the following performance levels at 100% design corrected speed.

	Stationary Diffuser	F. R. D.
Peak Pressure Ratio	7.91	7.43
Peak Adiabatic Efficiency %	72.6	70.0

Impeller efficiency and pressure ratio with the F. R. D. installed reduced 3.8% and from 10.1 to 9.25 respectively probably as a result of an eccentric radial clearance condition at the inducer entry.

Mechanical operation of the F. R. D. at impeller speed ratios between 0.30 to 0.4 was satisfactory, except that dynamic closure of the labyrinth tip seal did not occur even with the cold assembly radial gap reduced to 0.013 inch. Free rotating speed ratio did not change significantly as the flow was vaned from choke to surge at constant impeller speed.

Overall peak vaneless/vaned diffuser static pressure recovery with both the stationary and F. R. D. designs were essentially the same (approximately 0.61) at 100% design speed, indicating the possibility of tip seal flow leakage effects with the inability to obtain a rub-in seal operation.

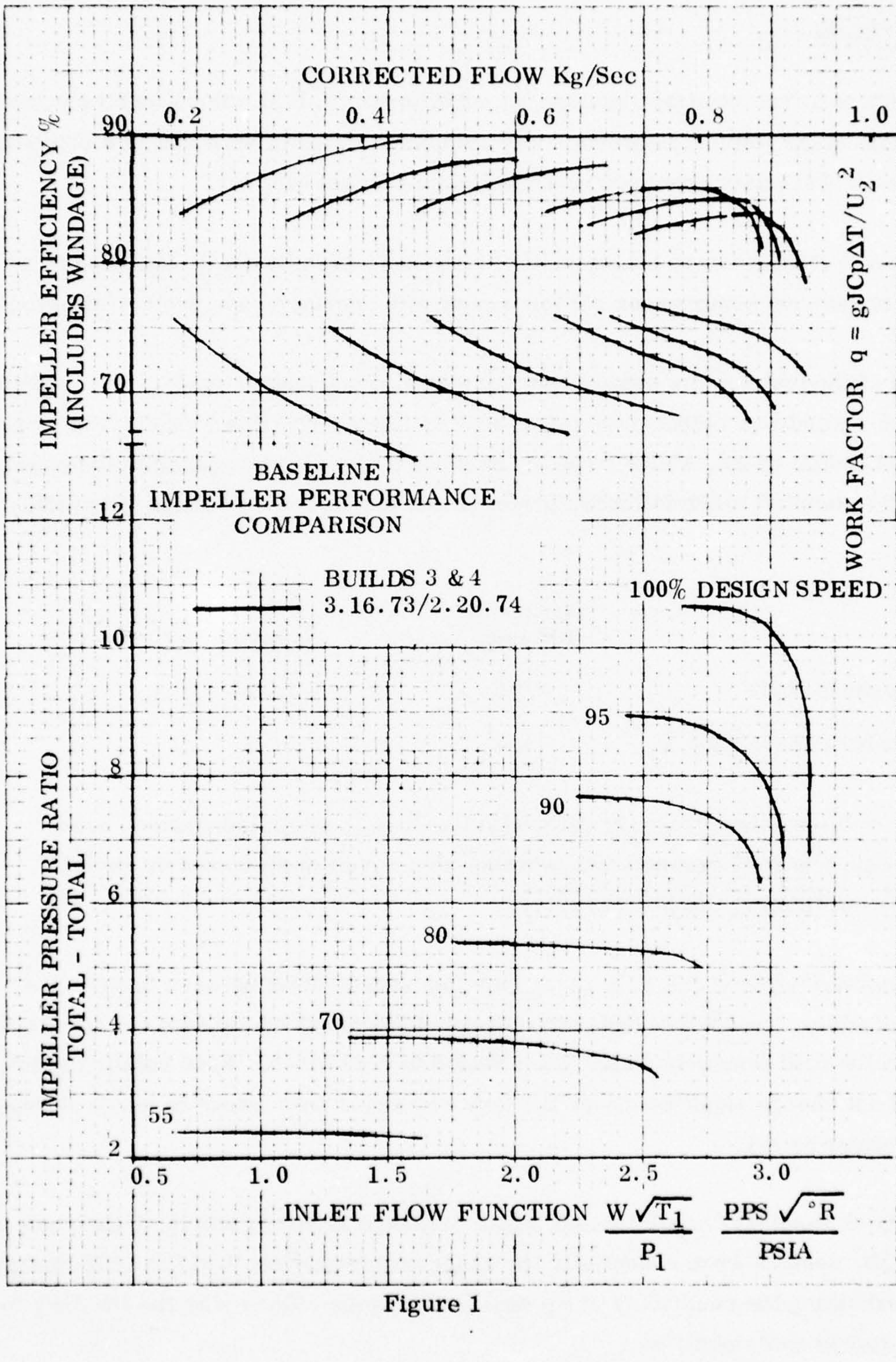
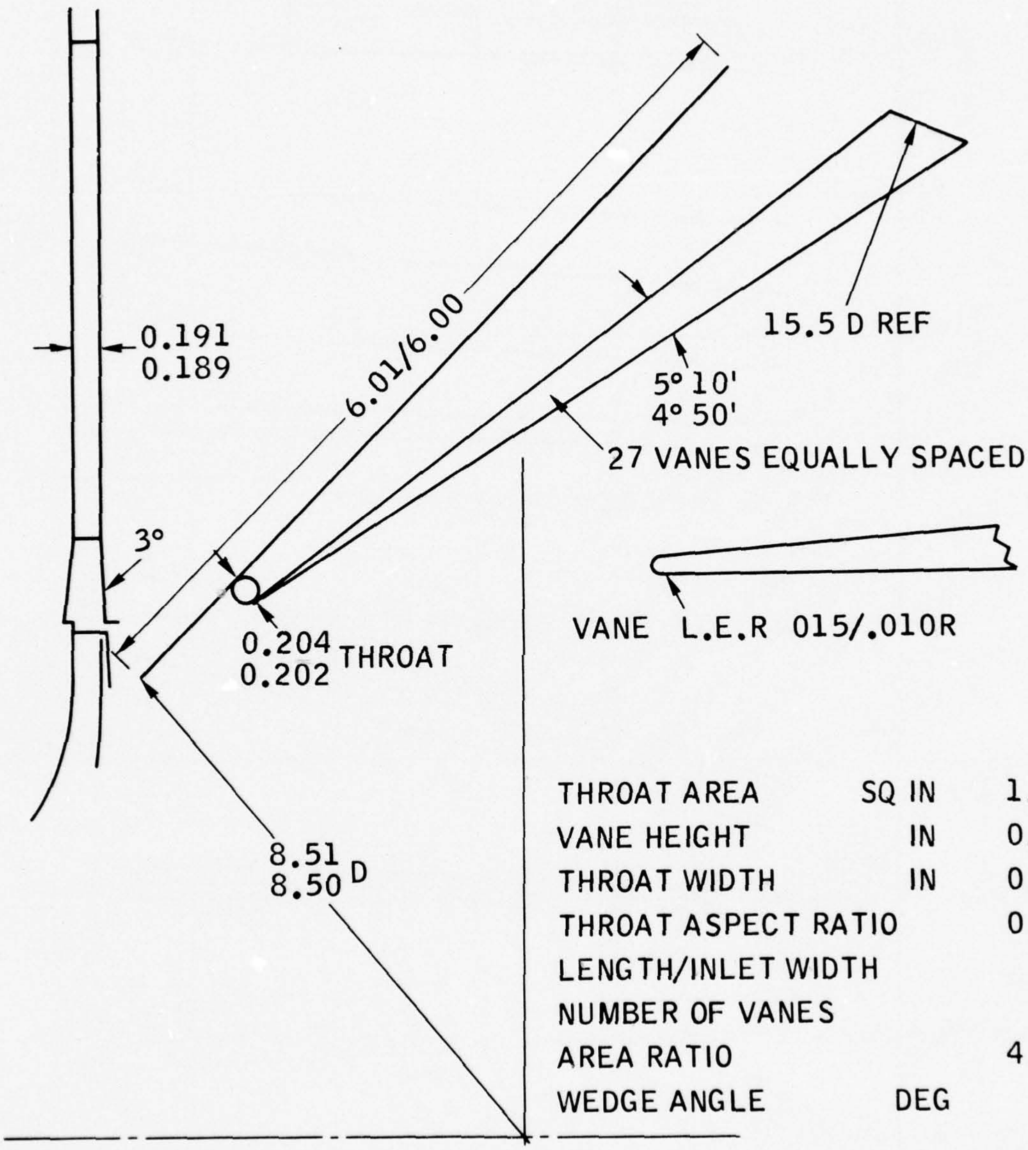
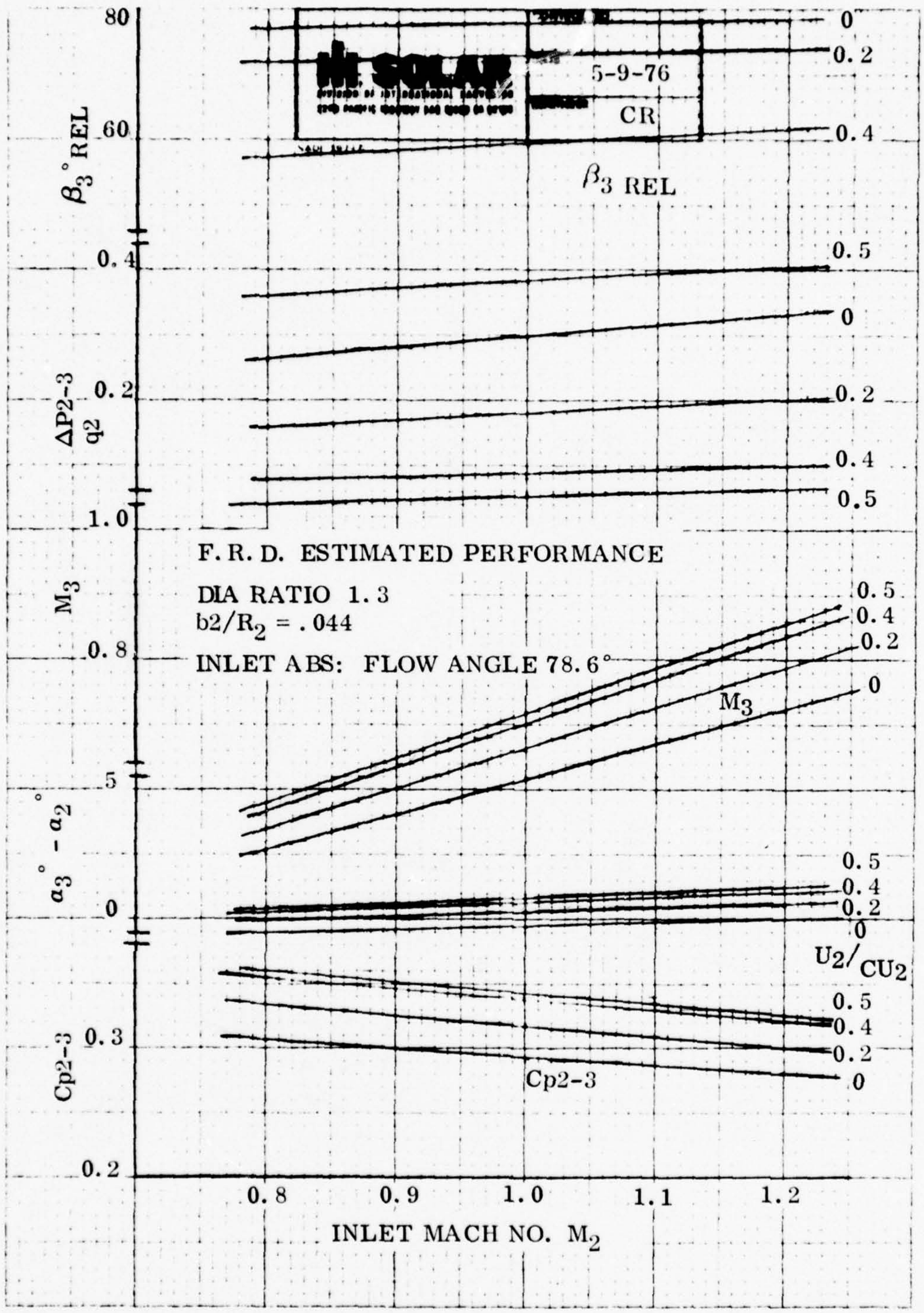

CORRECTED FLOW Kg/Sec
0.2
0.4
0.6
0.8
1.0
90
80
70
12
10
8
6
4
2
IMPELLER EFFICIENCY %
(INCLUDES WINDAGE)
WORK FACTOR q = gJCpΔT/U2^2
1.0
0.9
0.8
BASELINE
IMPELLER PERFORMANCE
COMPARISON
BUILDS 3 & 4
3.16.73/2.20.74
100% DESIGN SPEED
95
90
80
70
55
IMPELLER PRESSURE RATIO
TOTAL - TOTAL
0.5
1.0
1.5
2.0
2.5
3.0
INLET FLOW FUNCTION W √T1 / P1 PPS √°R / PSIA

Figure 1



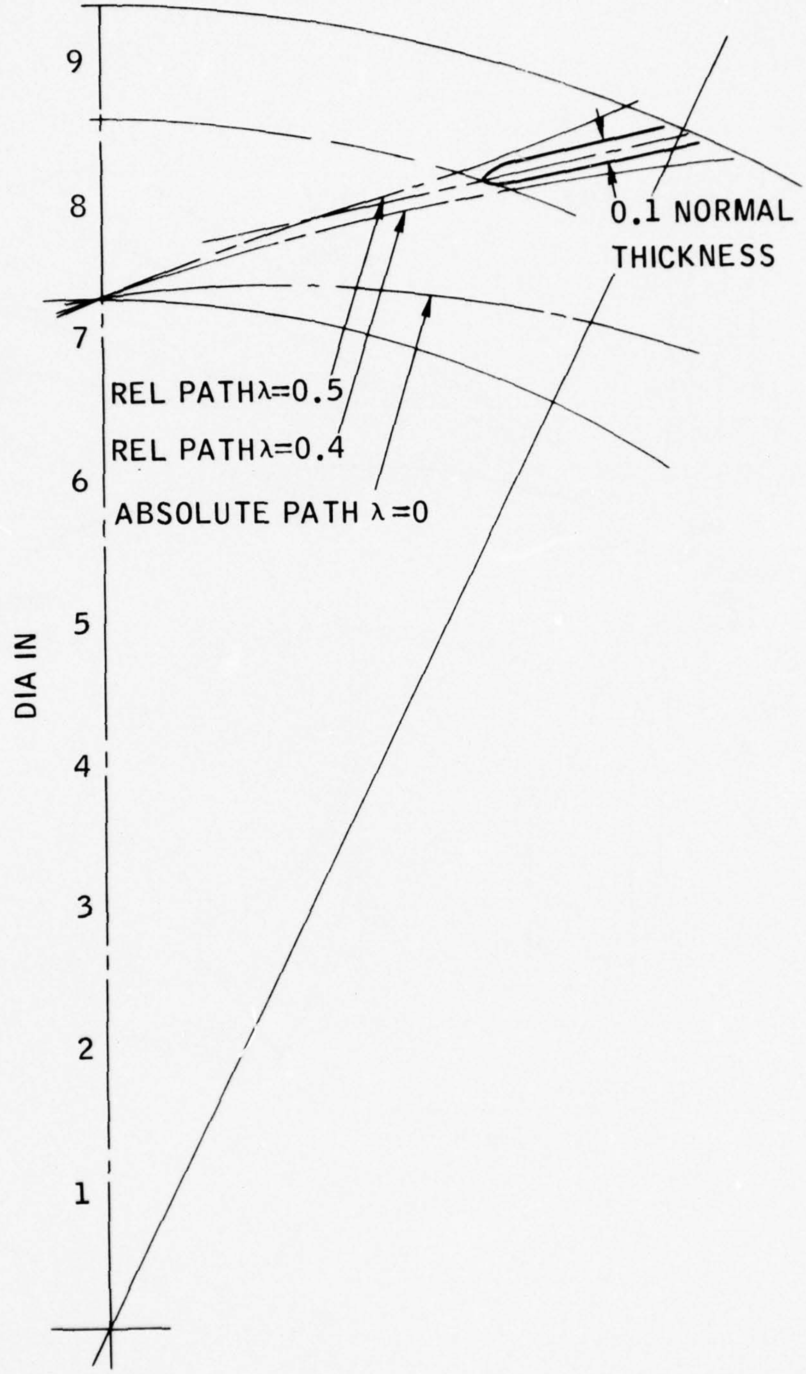
THROAT AREA	SQ IN	1.04
VANE HEIGHT	IN	0.19
THROAT WIDTH	IN	0.203
THROAT ASPECT RATIO		0.937
LENGTH/INLET WIDTH		25
NUMBER OF VANES		27
AREA RATIO		4.63
WEDGE ANGLE	DEG	5°

Figure 2



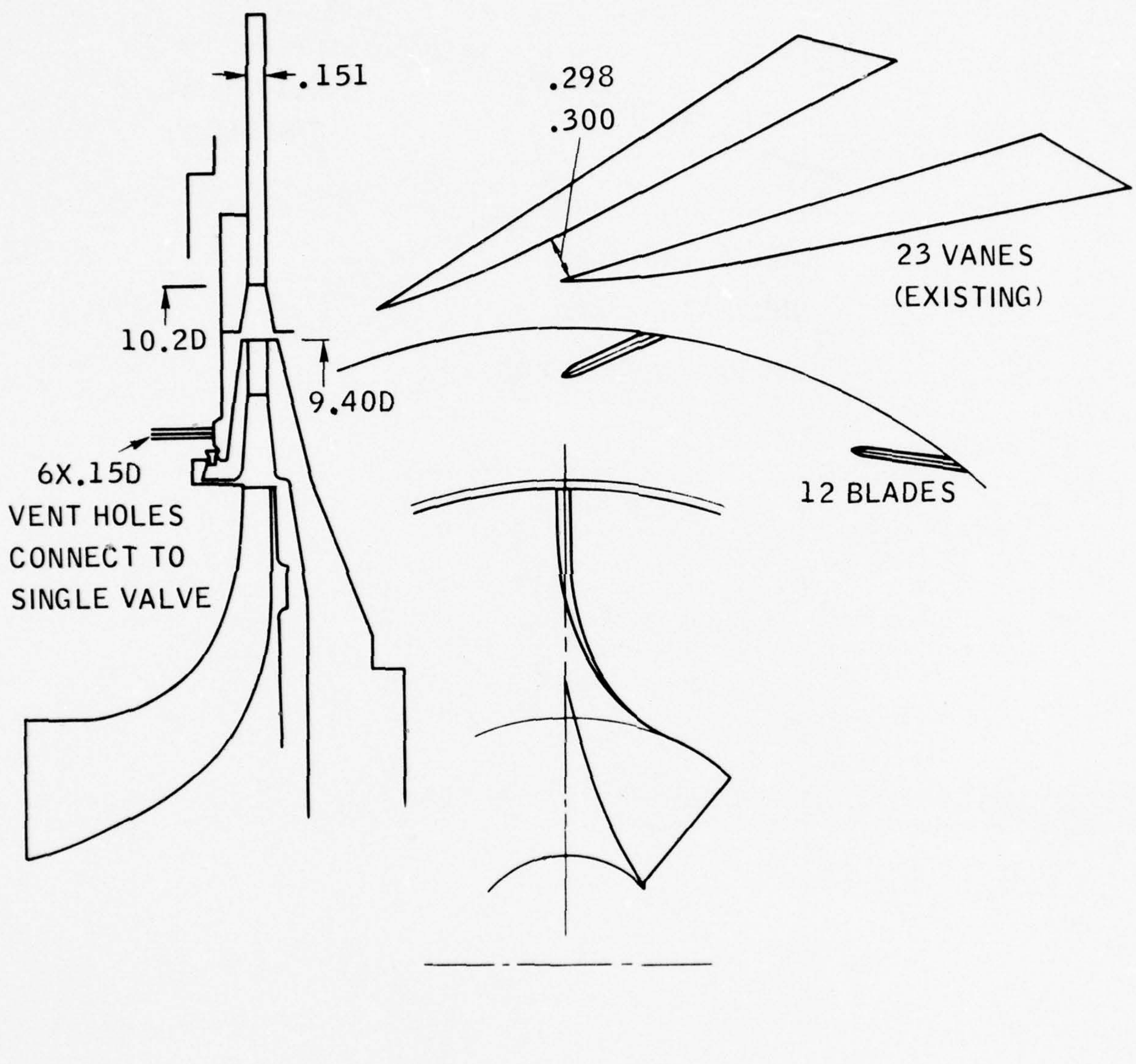
F. R. D. ESTIMATED PERFORMANCE
DIA RATIO 1.3
b2/R2 = .044
INLET ABS: FLOW ANGLE 78.6°
β3° REL
ΔP2-3 / q2
M3
α3° - α2°
Cp2-3
80
60
0.4
0.2
1.0
0.8
5
0
0.3
0.2
β3 REL
M3
Cp2-3
U2/CU2
0
0.2
0.4
0.5
0.8
0.9
1.0
1.1
1.2
INLET MACH NO. M2
SOLAR
5-9-76
CR

Figure 3



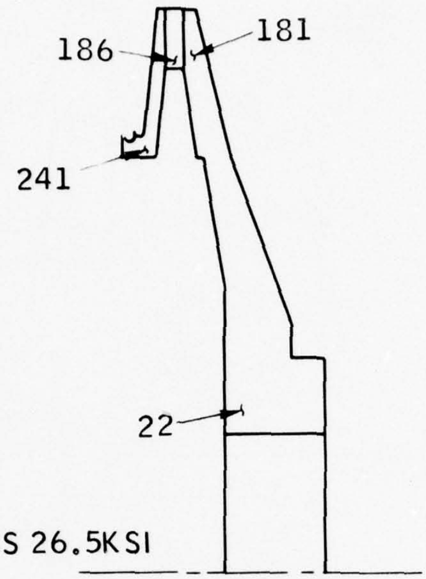
9
8
7
6
5
4
3
2
1
DIA IN
0.1 NORMAL
THICKNESS
REL PATH λ=0.5
REL PATH λ=0.4
ABSOLUTE PATH λ=0

Figure 4



.151
.298
.300
23 VANES
(EXISTING)
10.2D
9.40D
6X.15D
VENT HOLES
CONNECT TO
SINGLE VALVE
12 BLADES

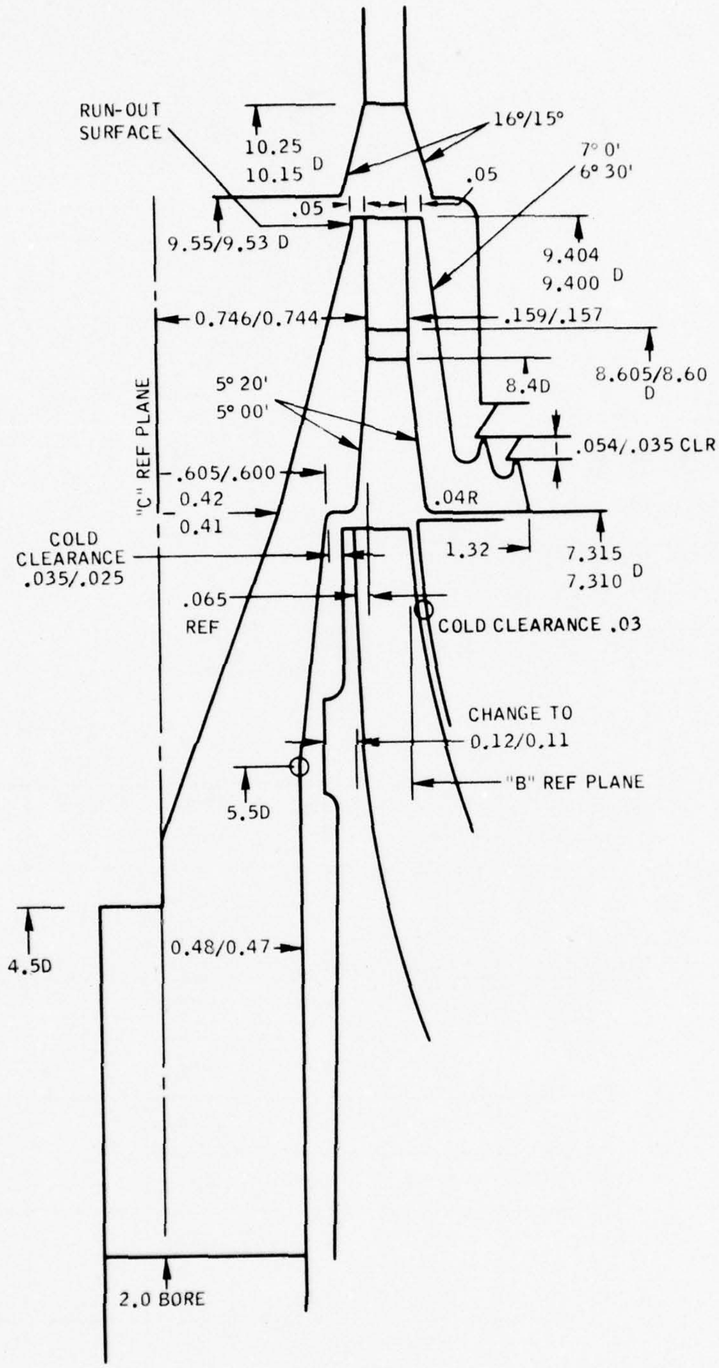
Figure 5



28,000 RPM
TITANIUM: 6Al 4V
WEIGHT 4.2 LB
Ip 37.8 LB IN^2
AVG $TANGT^L$ STRESS 26.5KSI

				12 BLADES	6 BLADES
NODE	TEMP	RADIAL GROWTH	AXIAL GROWTH	STRESS KSI	STRESS KSI
241	R.T	.019	.024	78.4	77.3
	500°F	.047	.045		
186	R.T	.012	.035	32.5	42.5
	500°F	.036	.067		
181	R.T	.009	.044	29.2	29.0
	500°F	.029	.085		
22	R.T	.003	.0003	51.7	51.5
	500°F	.009	.001		

Figure 6



RUN-OUT
SURFACE
10.25
10.15 D
16°/15°
7° 0'
6° 30'
.05
.05
9.55/9.53 D
9.404
9.400 D
0.746/0.744
.159/.157
8.605/8.60
D
8.4D
5° 20'
5° 00'
.054/.035 CLR
"C" REF PLANE
.605/.600
0.42
0.41
.04R
COLD
CLEARANCE
.035/.025
1.32
7.315
7.310 D
.065
REF
COLD CLEARANCE .03
CHANGE TO
0.12/0.11
"B" REF PLANE
5.5D
4.5D
0.48/0.47
2.0 BORE

Figure 7

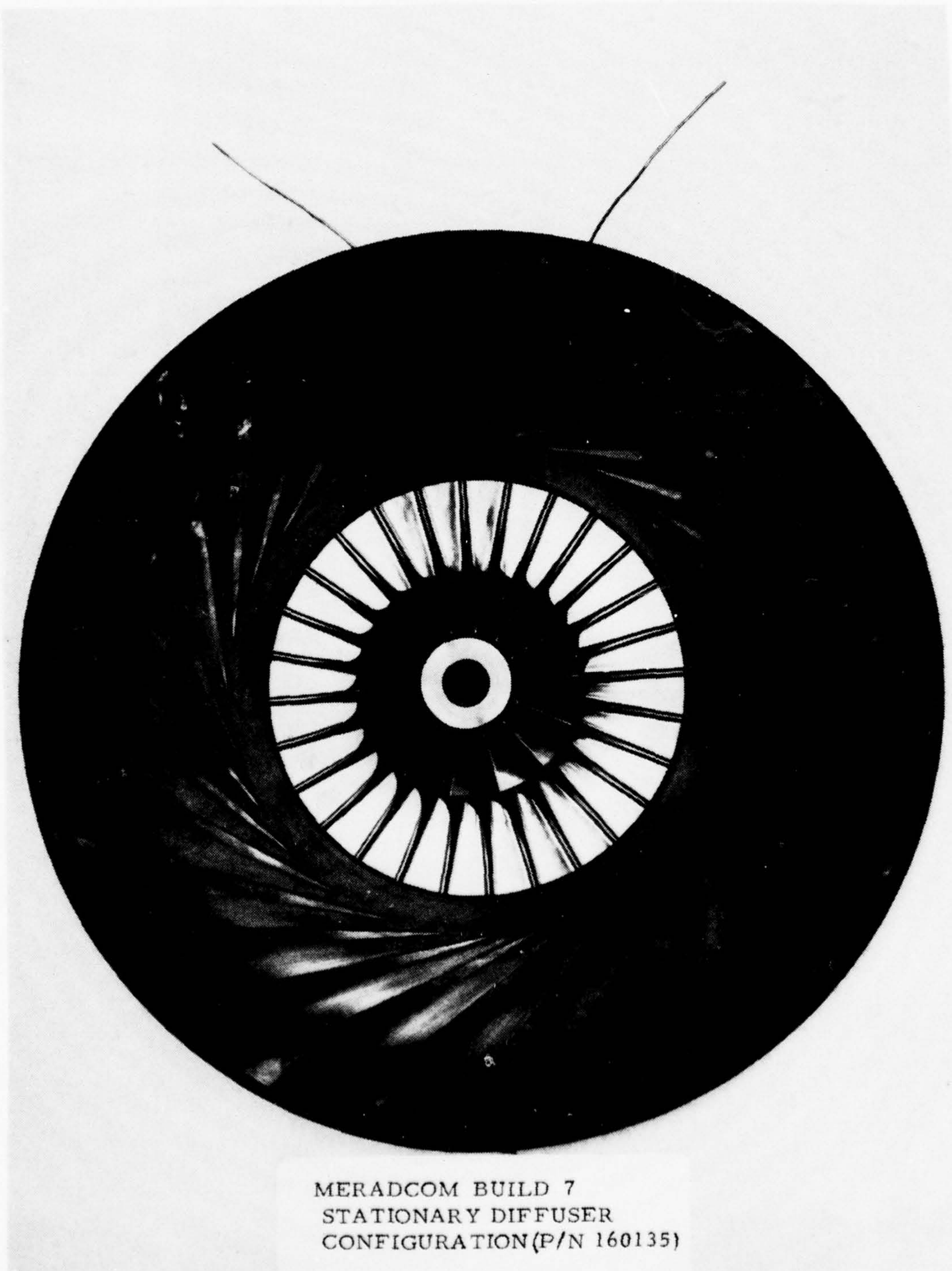

MERADCOM BUILD 7
STATIONARY DIFFUSER
CONFIGURATION(P/N 160135)

Figure 8

MERADCOM BUILD 8 DIFFUSER CONFIGURATION

Figure 9

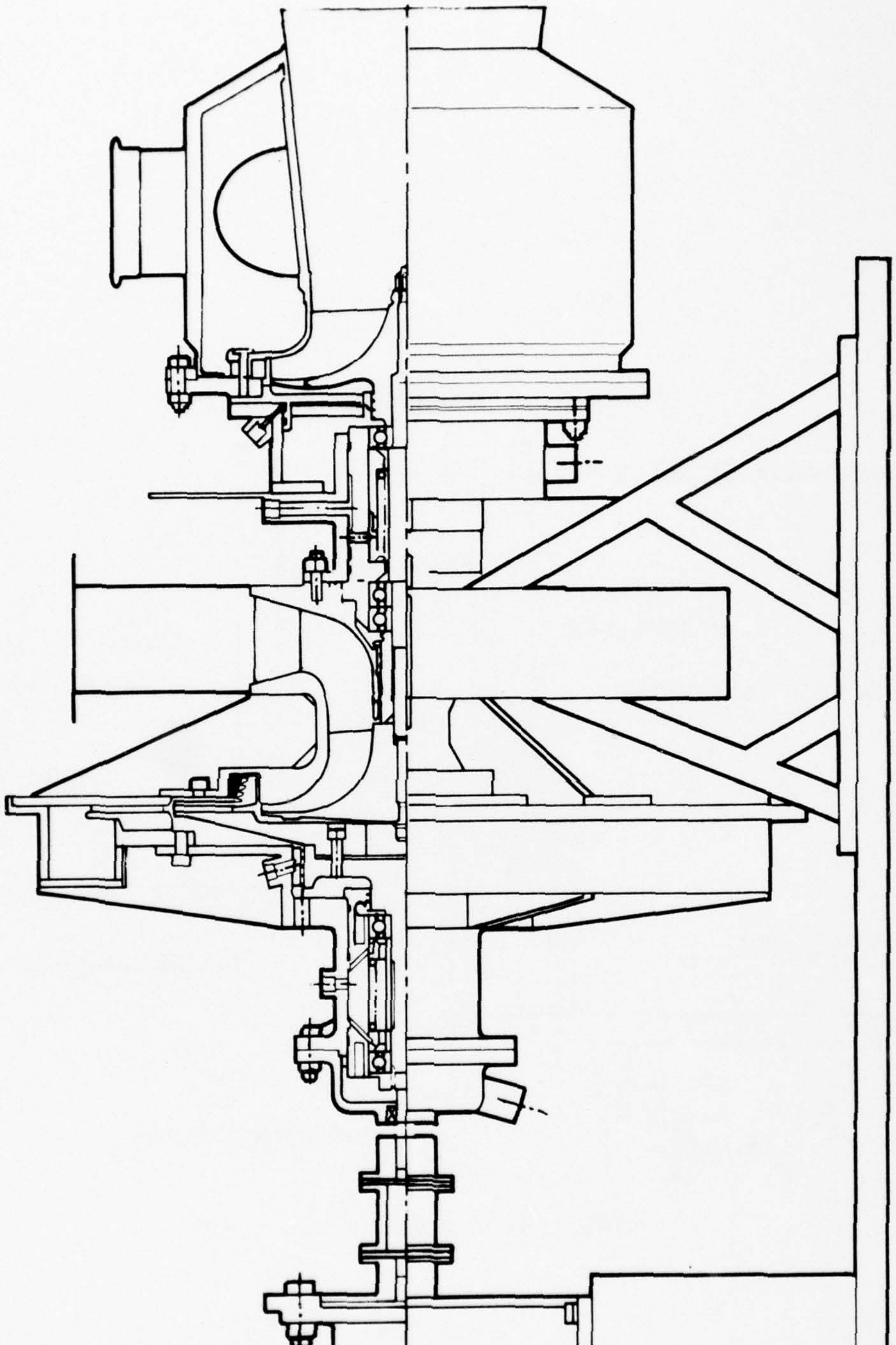


Figure 10

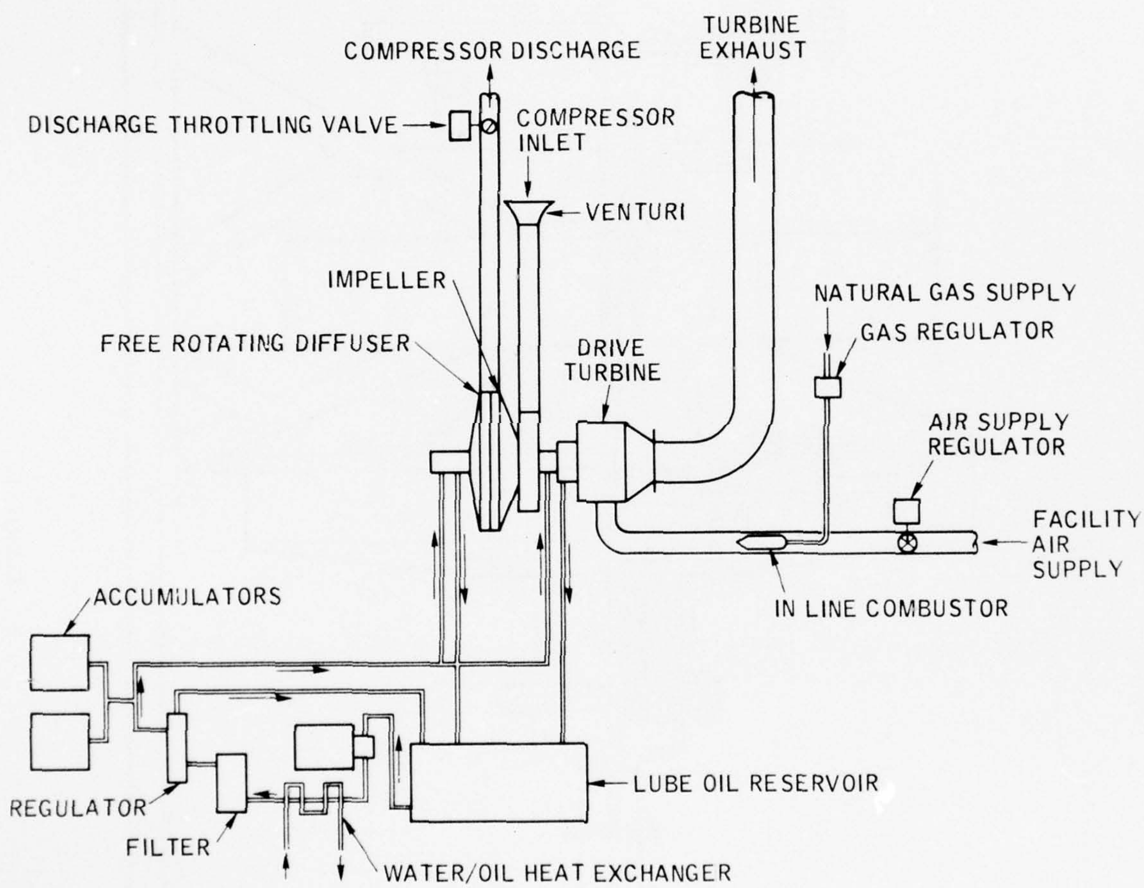

COMPRESSOR DISCHARGE
TURBINE EXHAUST
DISCHARGE THROTTLING VALVE
COMPRESSOR INLET
VENTURI
IMPELLER
NATURAL GAS SUPPLY
GAS REGULATOR
FREE ROTATING DIFFUSER
DRIVE TURBINE
AIR SUPPLY REGULATOR
FACILITY AIR SUPPLY
IN LINE COMBUSTOR
ACCUMULATORS
LUBE OIL RESERVOIR
REGULATOR
FILTER
WATER/OIL HEAT EXCHANGER

Figure 11

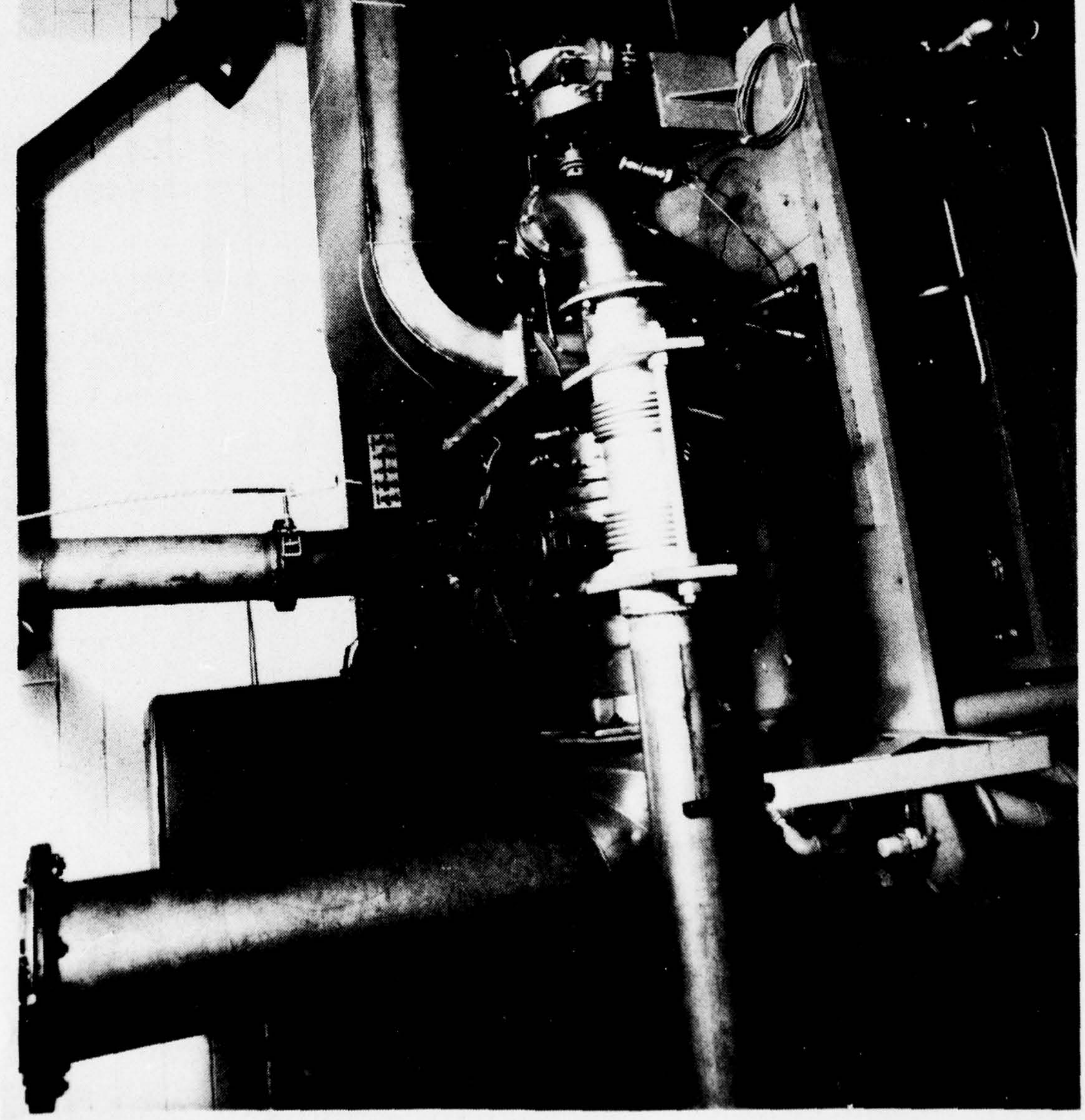


Figure 12

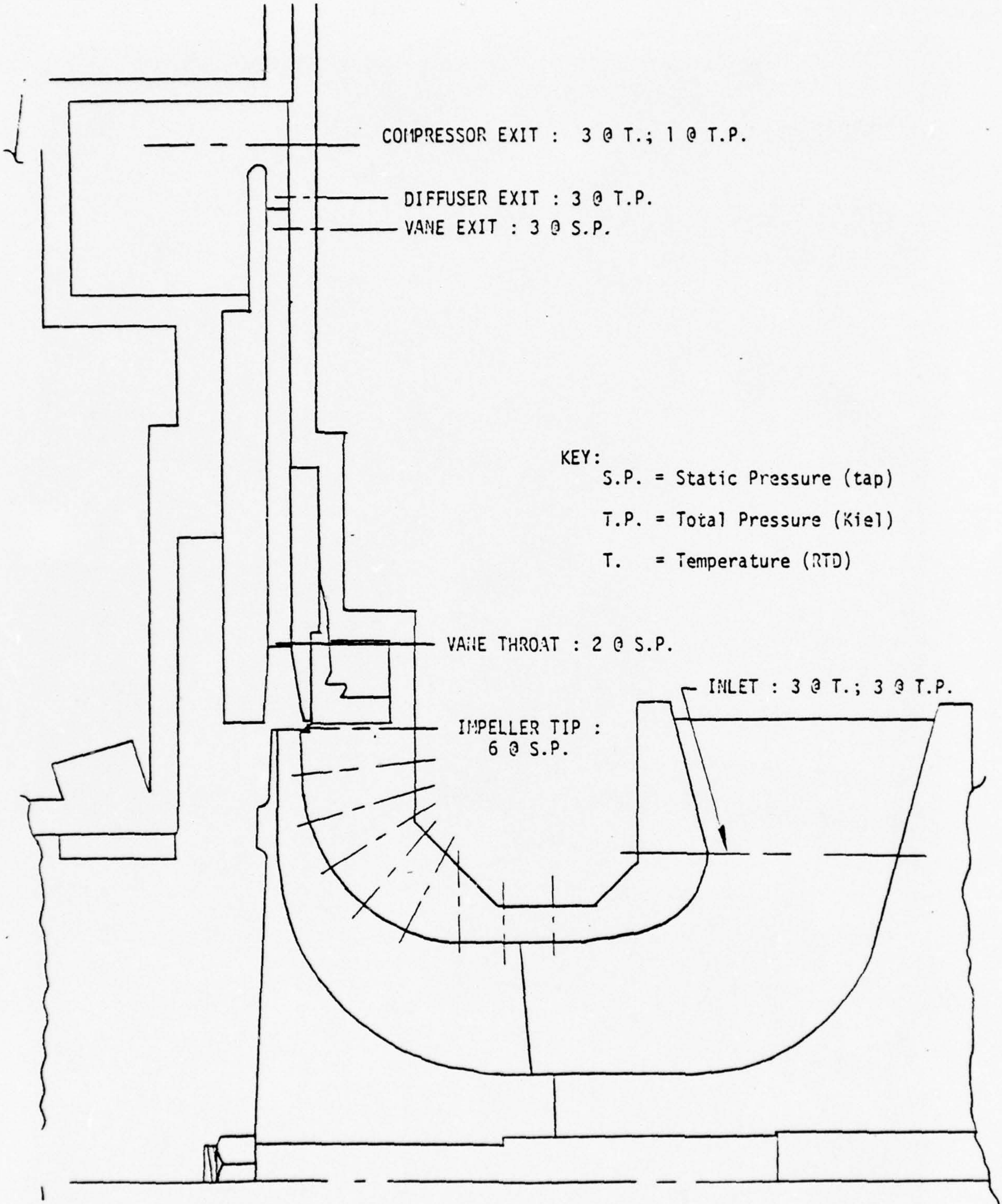


Figure 13 Stationary Vaned Diffuser Configuration Shroud/Diffuser Performance Instrumentation

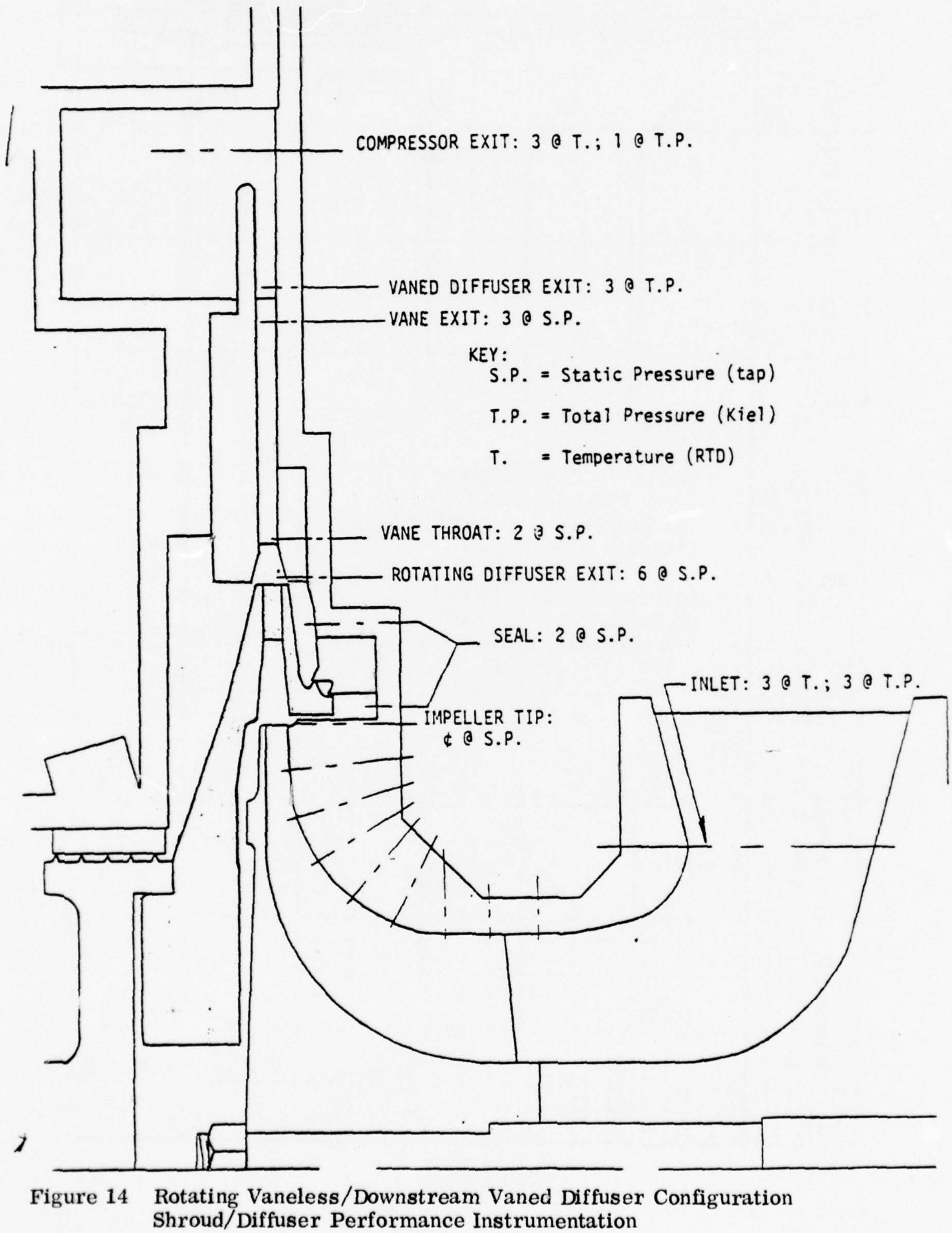


Figure 14 Rotating Vaneless/Downstream Vaned Diffuser Configuration Shroud/Diffuser Performance Instrumentation

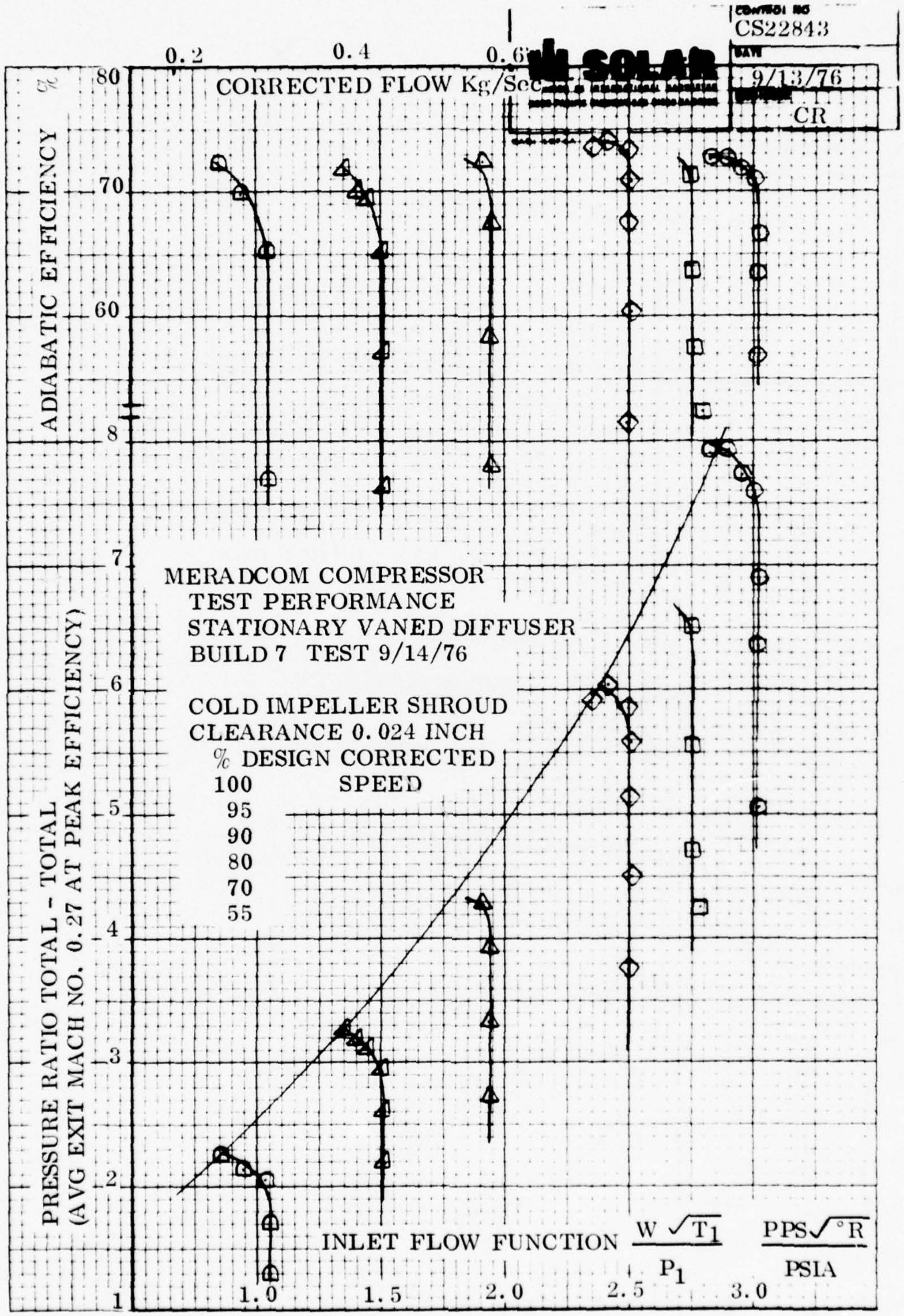
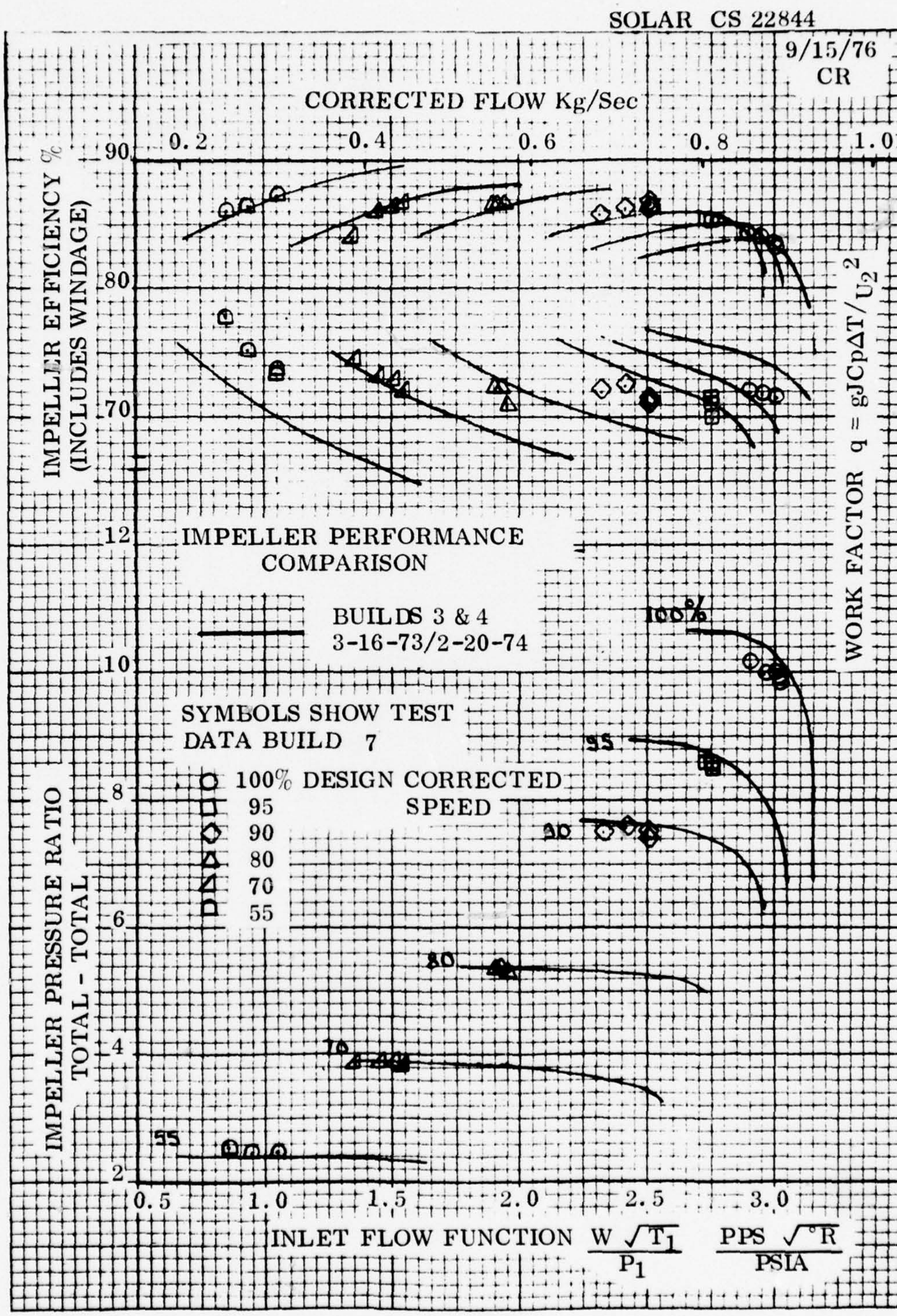

CONTROL NO
CS22843
DATE
9/13/76
CR
SOLAR
0.2
0.4
0.6
CORRECTED FLOW Kg/Sec
ADIABATIC EFFICIENCY %
80
70
60
8
7
6
5
4
3
2
1
MERADCOM COMPRESSOR
TEST PERFORMANCE
STATIONARY VANED DIFFUSER
BUILD 7 TEST 9/14/76
COLD IMPELLER SHROUD
CLEARANCE 0.024 INCH
% DESIGN CORRECTED
100 SPEED
95
90
80
70
55
PRESSURE RATIO TOTAL - TOTAL
(AVG EXIT MACH NO. 0.27 AT PEAK EFFICIENCY)
INLET FLOW FUNCTION W √T1 / P1 PPS√°R / PSIA
1.0
1.5
2.0
2.5
3.0

Figure 15



SOLAR CS 22844
9/15/76
CR
CORRECTED FLOW Kg/Sec
0.2
0.4
0.6
0.8
1.0
90
80
70
12
10
8
6
4
2
IMPELLER EFFICIENCY %
(INCLUDES WINDAGE)
WORK FACTOR $q = gJCp\Delta T/U_2^2$
1.0
0.9
0.8
IMPELLER PERFORMANCE
COMPARISON
BUILDS 3 & 4
3-16-73/2-20-74
SYMBOLS SHOW TEST
DATA BUILD 7
100% DESIGN CORRECTED
95 SPEED
90
80
70
55
100%
95
90
80
70
55
IMPELLER PRESSURE RATIO
TOTAL - TOTAL
0.5
1.0
1.5
2.0
2.5
3.0
INLET FLOW FUNCTION $\frac{W\sqrt{T_1}}{P_1}$ $\frac{PPS\ \sqrt{°R}}{PSIA}$

Figure 16

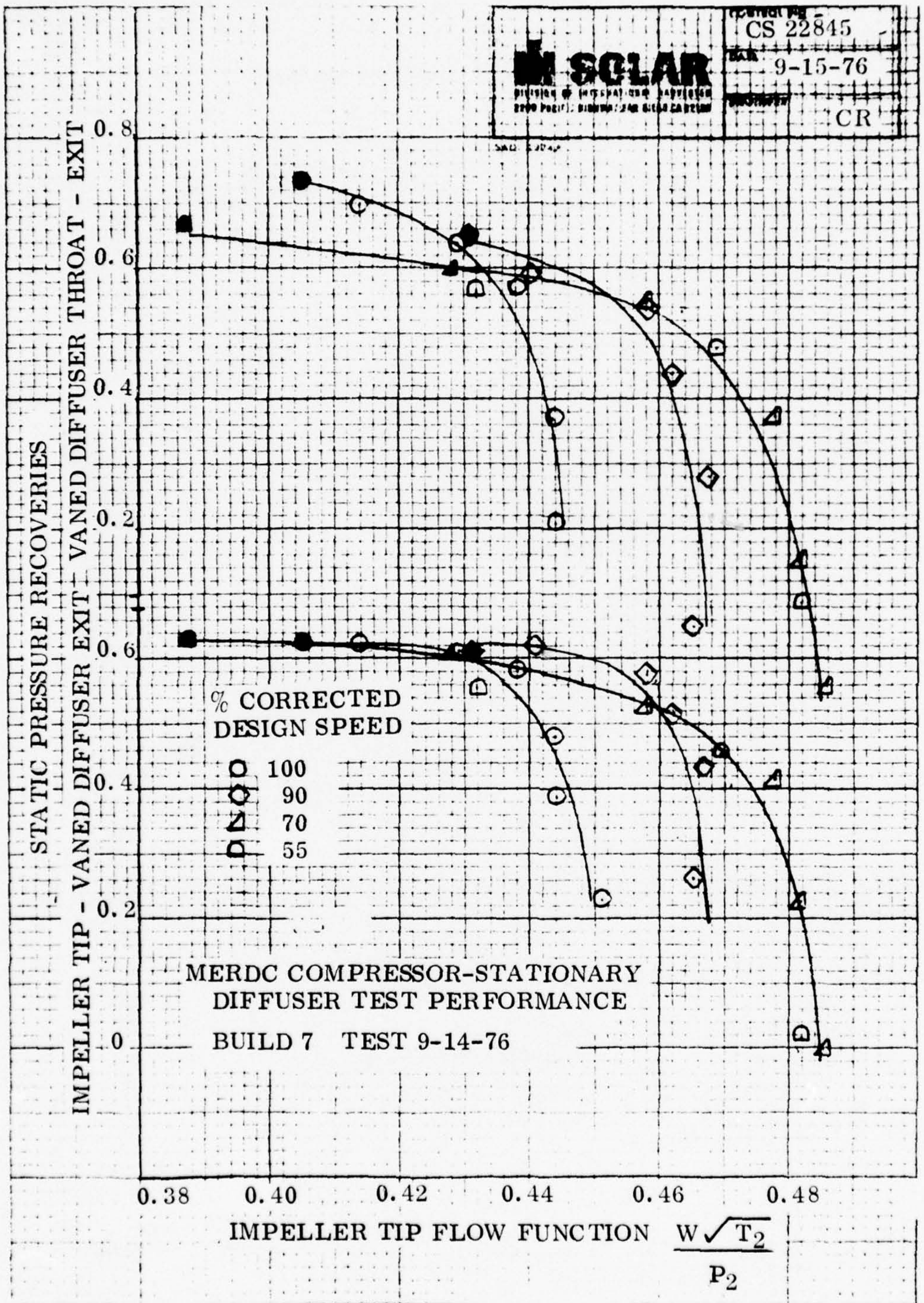
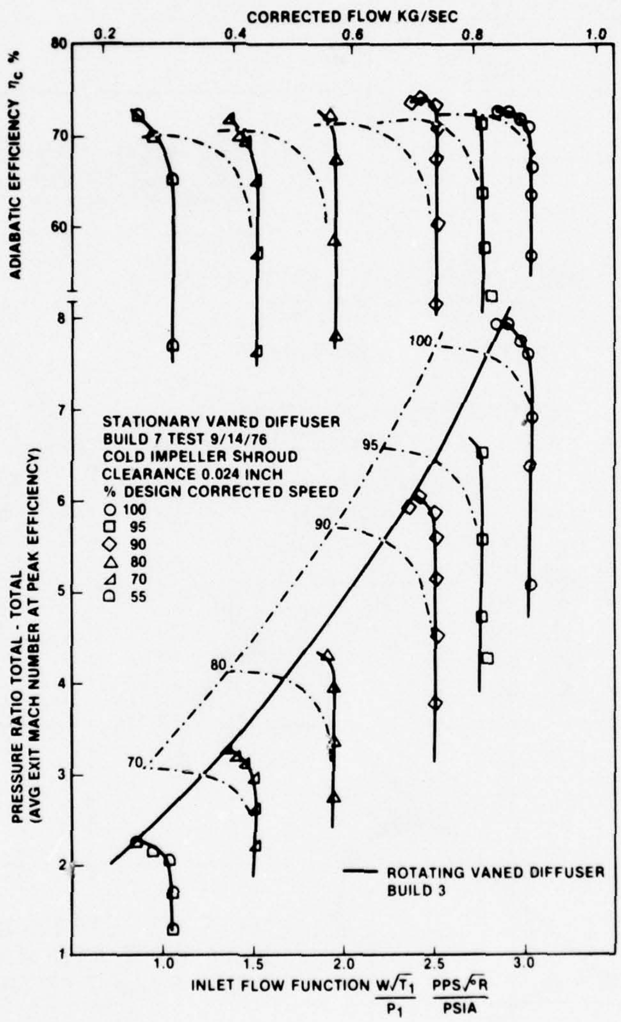

CS 22845
9-15-76
CR
SOLAR
0.8
0.6
0.4
0.2
0.6
0.4
0.2
0
STATIC PRESSURE RECOVERIES
IMPELLER TIP - VANED DIFFUSER EXIT - VANED DIFFUSER THROAT - EXIT
% CORRECTED DESIGN SPEED
100
90
70
55
MERDC COMPRESSOR-STATIONARY DIFFUSER TEST PERFORMANCE
BUILD 7 TEST 9-14-76
0.38
0.40
0.42
0.44
0.46
0.48
IMPELLER TIP FLOW FUNCTION $\frac{W\sqrt{T_2}}{P_2}$

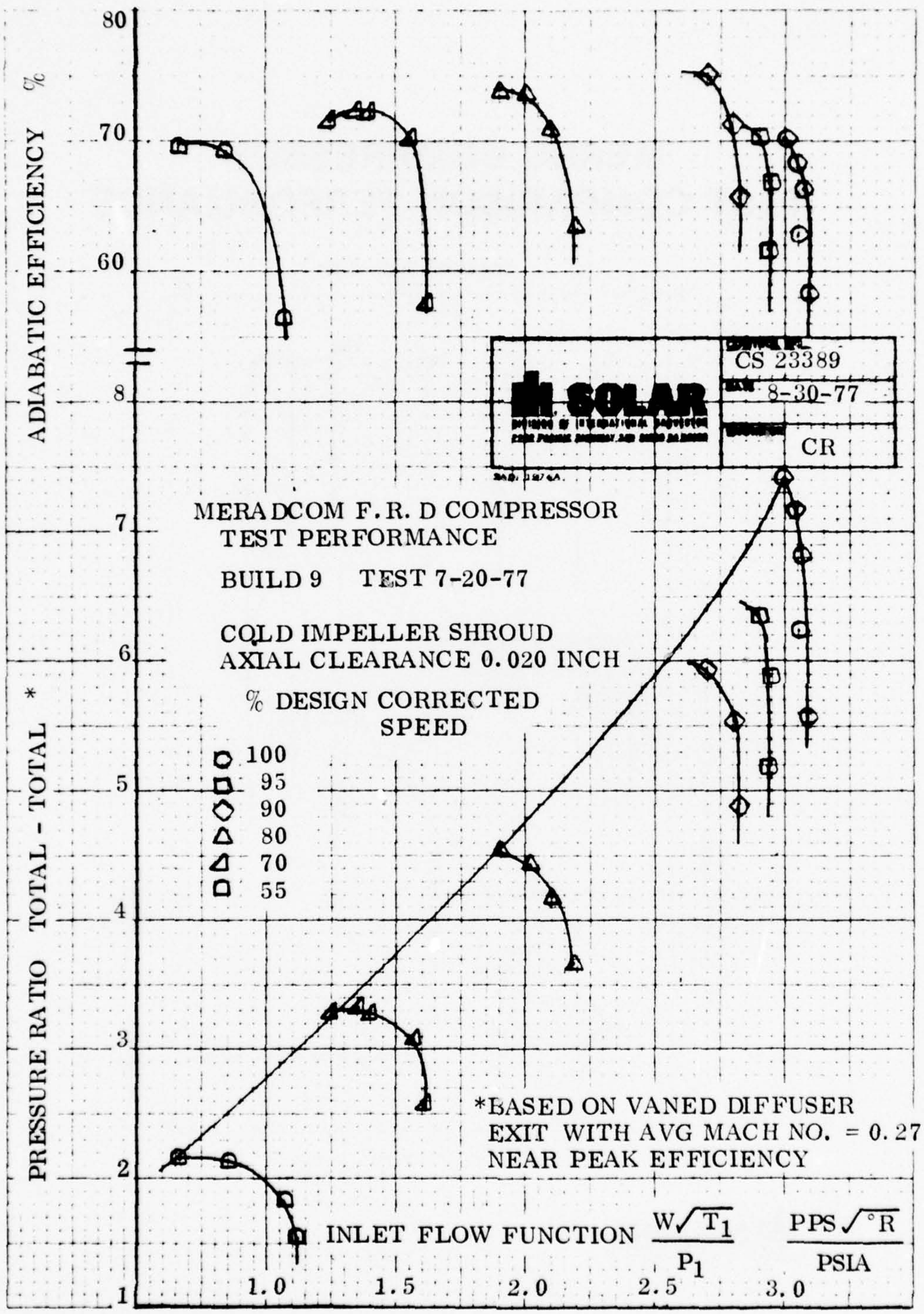
Figure 17

MERDC COMPRESSOR TEST COMPARISON PERFORMANCE



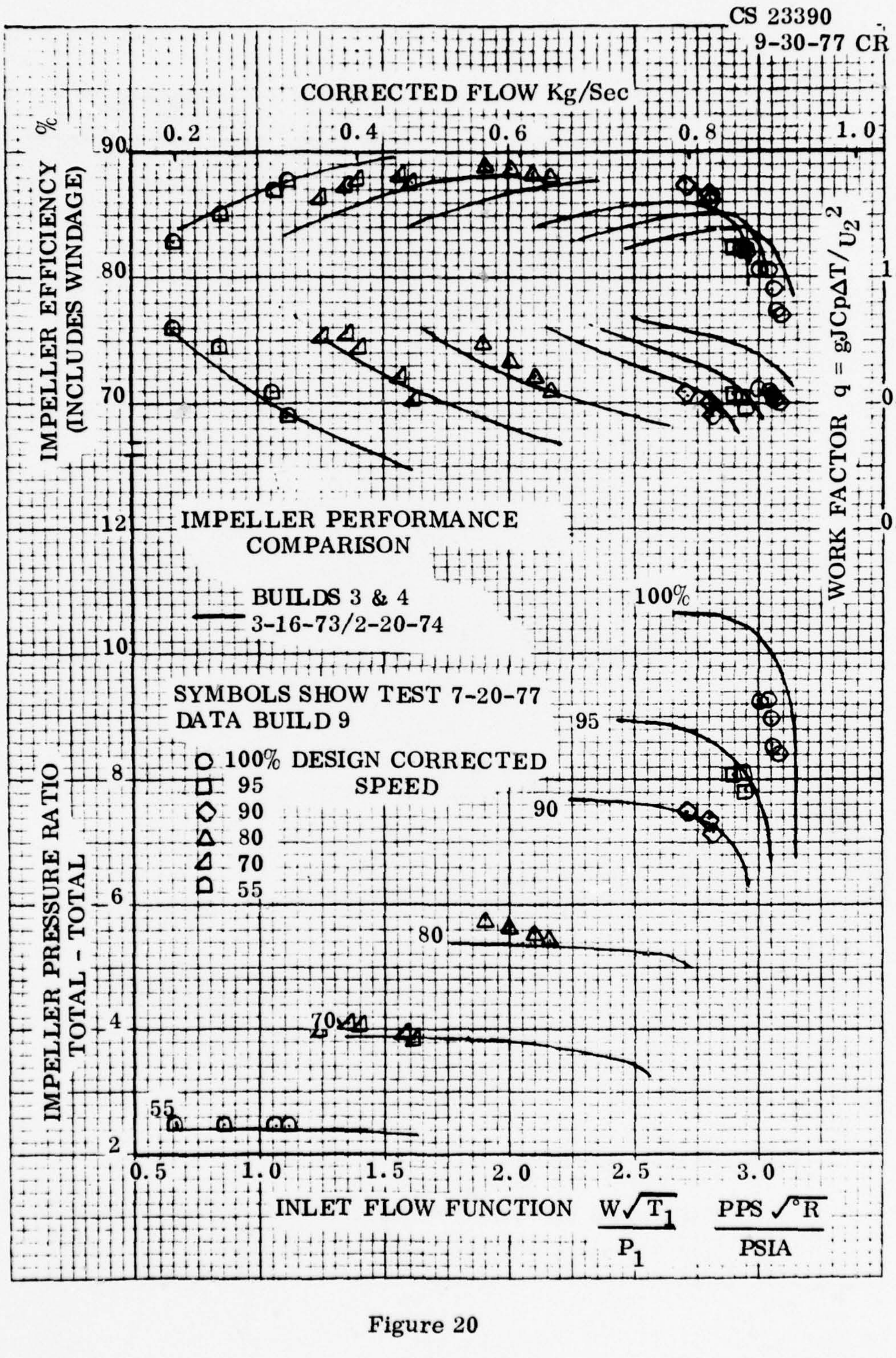
IH SOLAR
DIVISION OF INTERNATIONAL HARVESTER

Figure 18



80
70
60
8
7
6
5
4
3
2
1
ADIABATIC EFFICIENCY %
PRESSURE RATIO TOTAL - TOTAL *
CS 23389
8-30-77
CR
SOLAR
MERADCOM F.R.D COMPRESSOR
TEST PERFORMANCE
BUILD 9 TEST 7-20-77
COLD IMPELLER SHROUD
AXIAL CLEARANCE 0.020 INCH
% DESIGN CORRECTED
SPEED
100
95
90
80
70
55
*BASED ON VANED DIFFUSER
EXIT WITH AVG MACH NO. = 0.27
NEAR PEAK EFFICIENCY
INLET FLOW FUNCTION W√T1 / P1 PPS √°R / PSIA
1.0
1.5
2.0
2.5
3.0

Figure 19



CS 23390
9-30-77 CR
CORRECTED FLOW Kg/Sec
0.2
0.4
0.6
0.8
1.0
IMPELLER EFFICIENCY %
(INCLUDES WINDAGE)
90
80
70
WORK FACTOR q = gJCpΔT/U2^2
1.0
0.9
0.8
IMPELLER PERFORMANCE
COMPARISON
BUILDS 3 & 4
3-16-73/2-20-74
SYMBOLS SHOW TEST 7-20-77
DATA BUILD 9
100% DESIGN CORRECTED
95
90
80
70
55
SPEED
IMPELLER PRESSURE RATIO
TOTAL - TOTAL
12
10
8
6
4
2
100%
95
90
80
70
55
0.5
1.0
1.5
2.0
2.5
3.0
INLET FLOW FUNCTION W√T1 / P1 PPS √°R / PSIA

Figure 20

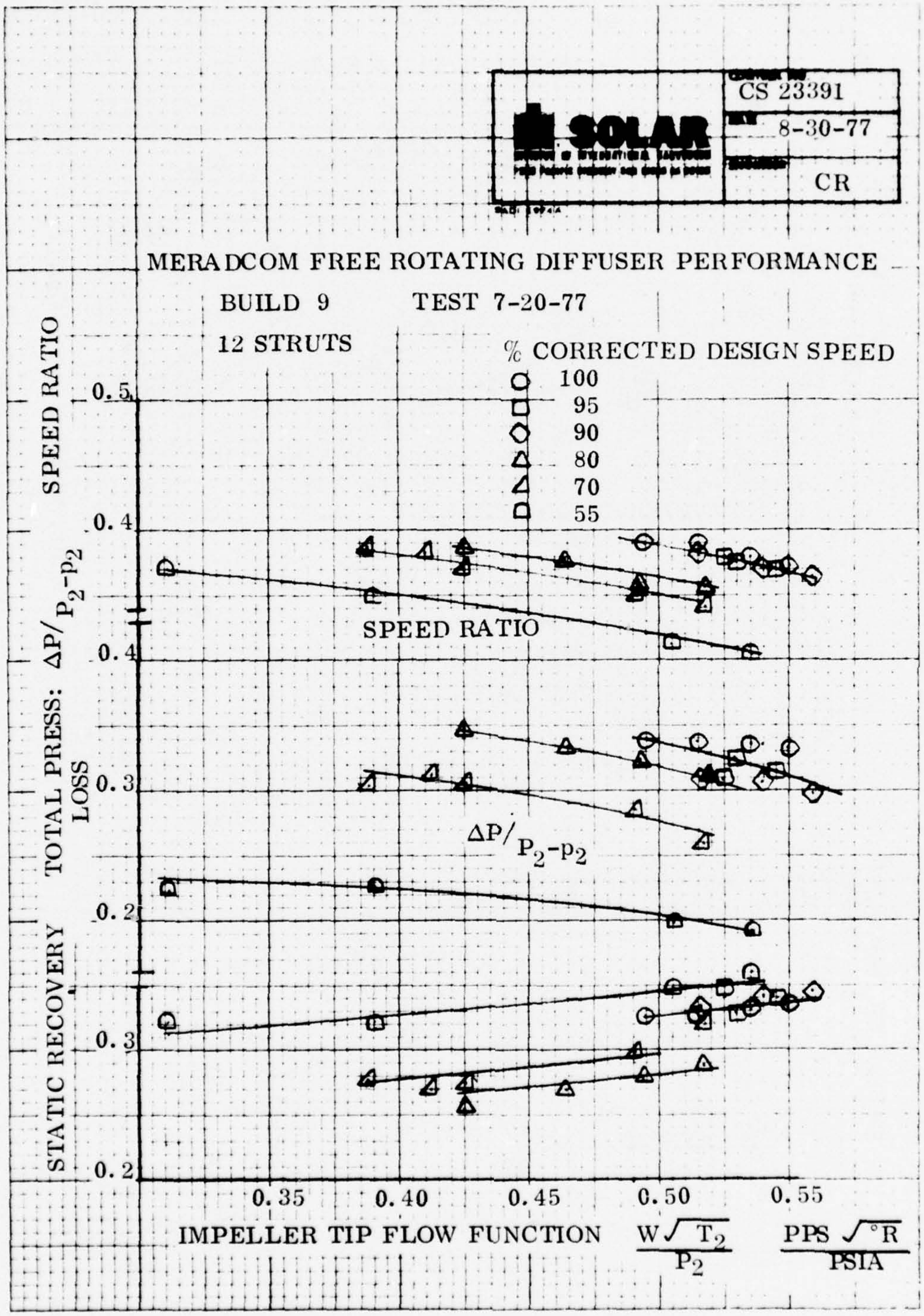

CS 23391
8-30-77
CR
SOLAR
MERADCOM FREE ROTATING DIFFUSER PERFORMANCE
BUILD 9 TEST 7-20-77
12 STRUTS
% CORRECTED DESIGN SPEED
100
95
90
80
70
55
SPEED RATIO
TOTAL PRESS: ΔP/P2-p2 LOSS
STATIC RECOVERY
SPEED RATIO
ΔP/P2-p2
0.5
0.4
0.4
0.3
0.2
0.3
0.2
0.35
0.40
0.45
0.50
0.55
IMPELLER TIP FLOW FUNCTION W√T2/P2 PPS √°R/PSIA

Figure 21

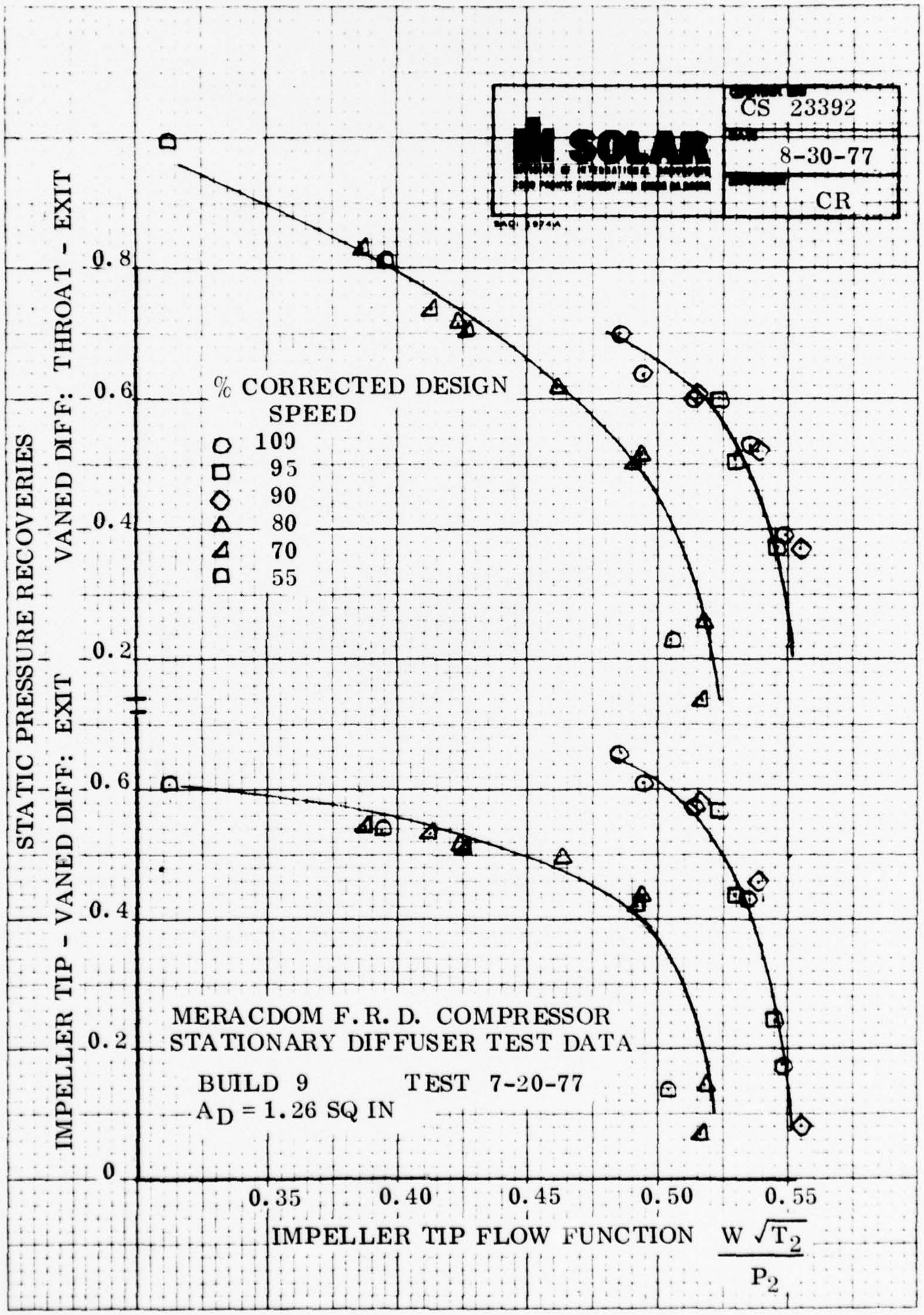

CS 23392
8-30-77
CR
SOLAR
STATIC PRESSURE RECOVERIES
IMPELLER TIP - VANED DIFF: EXIT
VANED DIFF: THROAT - EXIT
% CORRECTED DESIGN SPEED
100
95
90
80
70
55
MERACDOM F.R.D. COMPRESSOR
STATIONARY DIFFUSER TEST DATA
BUILD 9
TEST 7-20-77
A_D = 1.26 SQ IN
0.8
0.6
0.4
0.2
0
0.35
0.40
0.45
0.50
0.55
IMPELLER TIP FLOW FUNCTION $\frac{W\sqrt{T_2}}{P_2}$

Figure 22

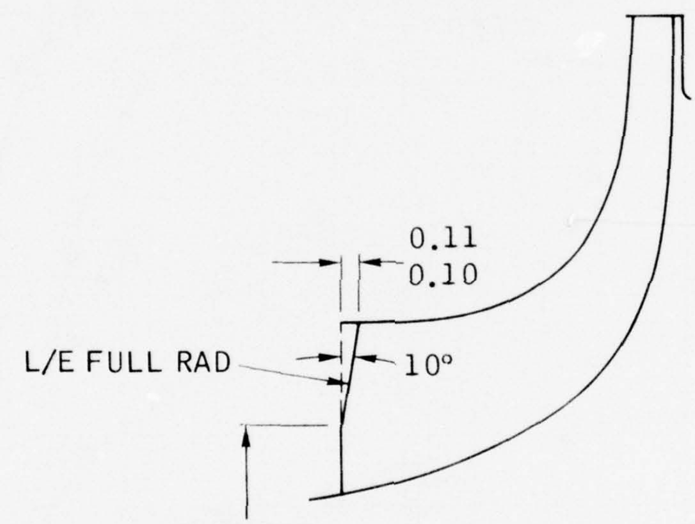


Figure 23

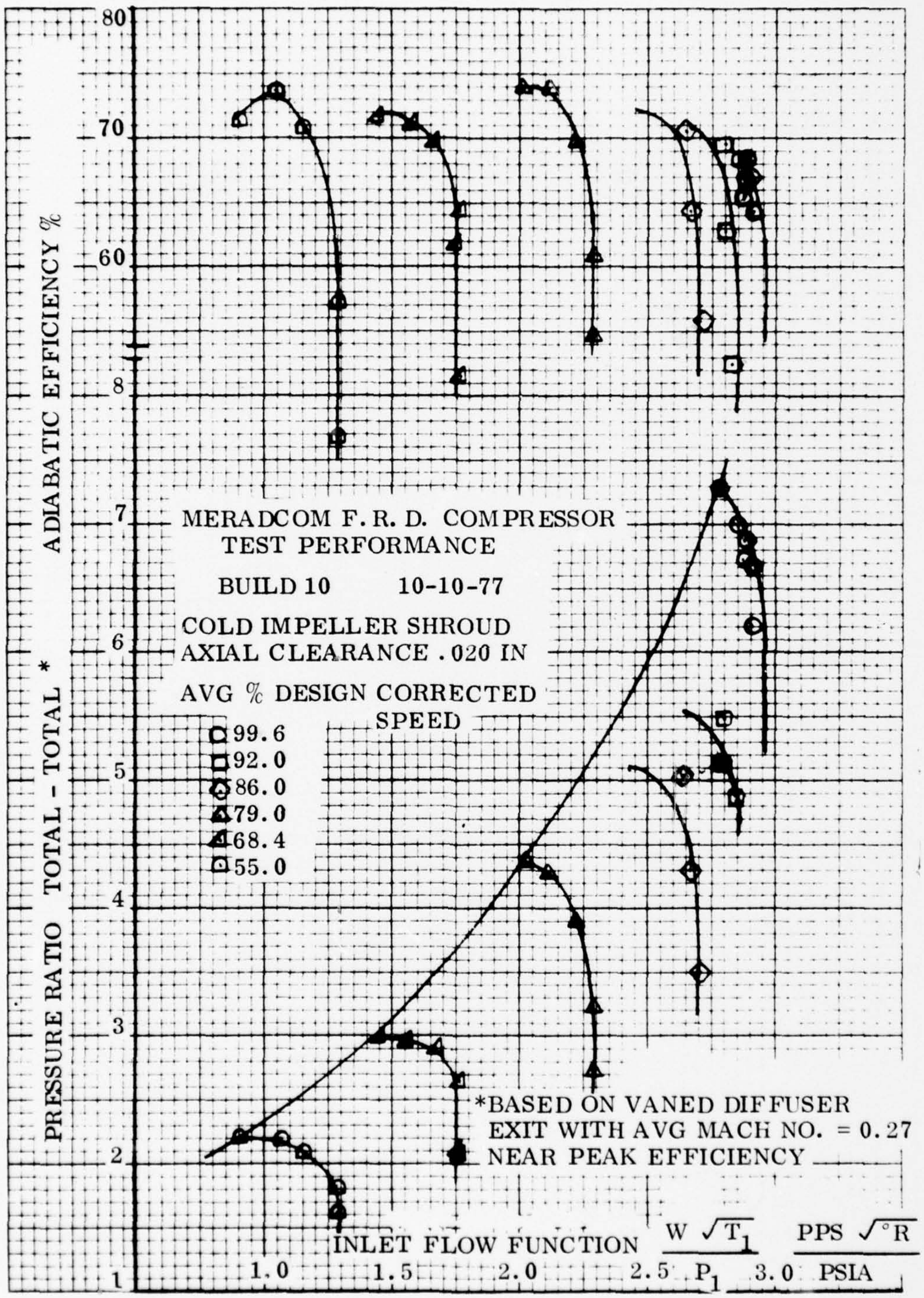

MERADCOM F. R. D. COMPRESSOR
TEST PERFORMANCE
BUILD 10 10-10-77
COLD IMPELLER SHROUD
AXIAL CLEARANCE .020 IN
AVG % DESIGN CORRECTED SPEED
99.6
92.0
86.0
79.0
68.4
55.0
*BASED ON VANED DIFFUSER
EXIT WITH AVG MACH NO. = 0.27
NEAR PEAK EFFICIENCY
PRESSURE RATIO TOTAL - TOTAL *
ADIABATIC EFFICIENCY %
INLET FLOW FUNCTION $\frac{W\sqrt{T_1}}{P_1}$ $\frac{PPS\sqrt{°R}}{PSIA}$
80
70
60
8
7
6
5
4
3
2
1
1.0
1.5
2.0
2.5
3.0

Figure 24

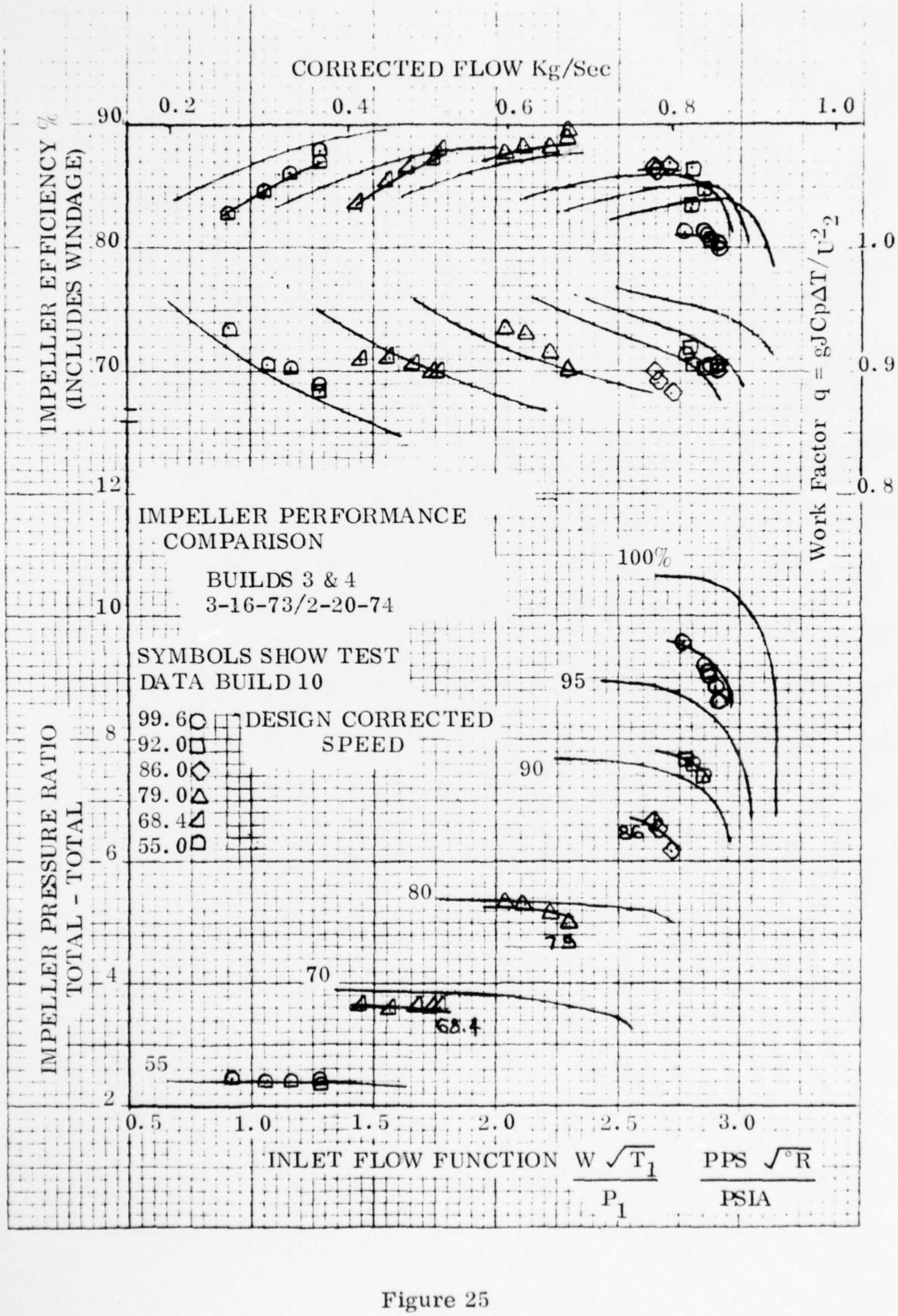

CORRECTED FLOW Kg/Sec
0.2
0.4
0.6
0.8
1.0
IMPELLER EFFICIENCY %
(INCLUDES WINDAGE)
90
80
70
Work Factor q = gJCpΔT/U²₂
1.0
0.9
0.8
IMPELLER PERFORMANCE COMPARISON
BUILDS 3 & 4
3-16-73/2-20-74
SYMBOLS SHOW TEST DATA BUILD 10
99.6
92.0
86.0
79.0
68.4
55.0
DESIGN CORRECTED SPEED
100%
95
90
86
80
79
70
68.4
55
IMPELLER PRESSURE RATIO
TOTAL - TOTAL
12
10
8
6
4
2
0.5
1.0
1.5
2.0
2.5
3.0
INLET FLOW FUNCTION W √T1 / P1 PPS √°R / PSIA

Figure 25

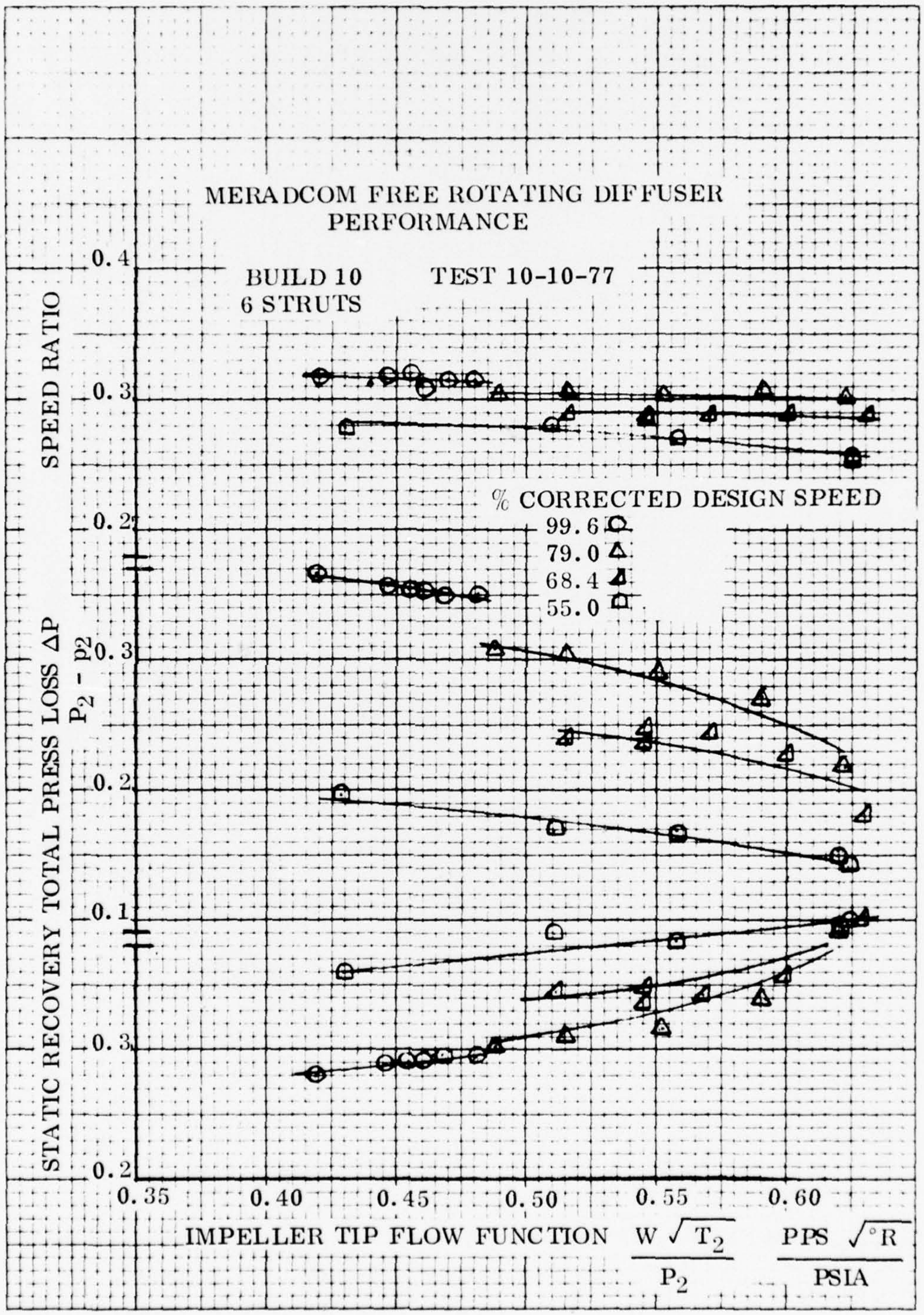
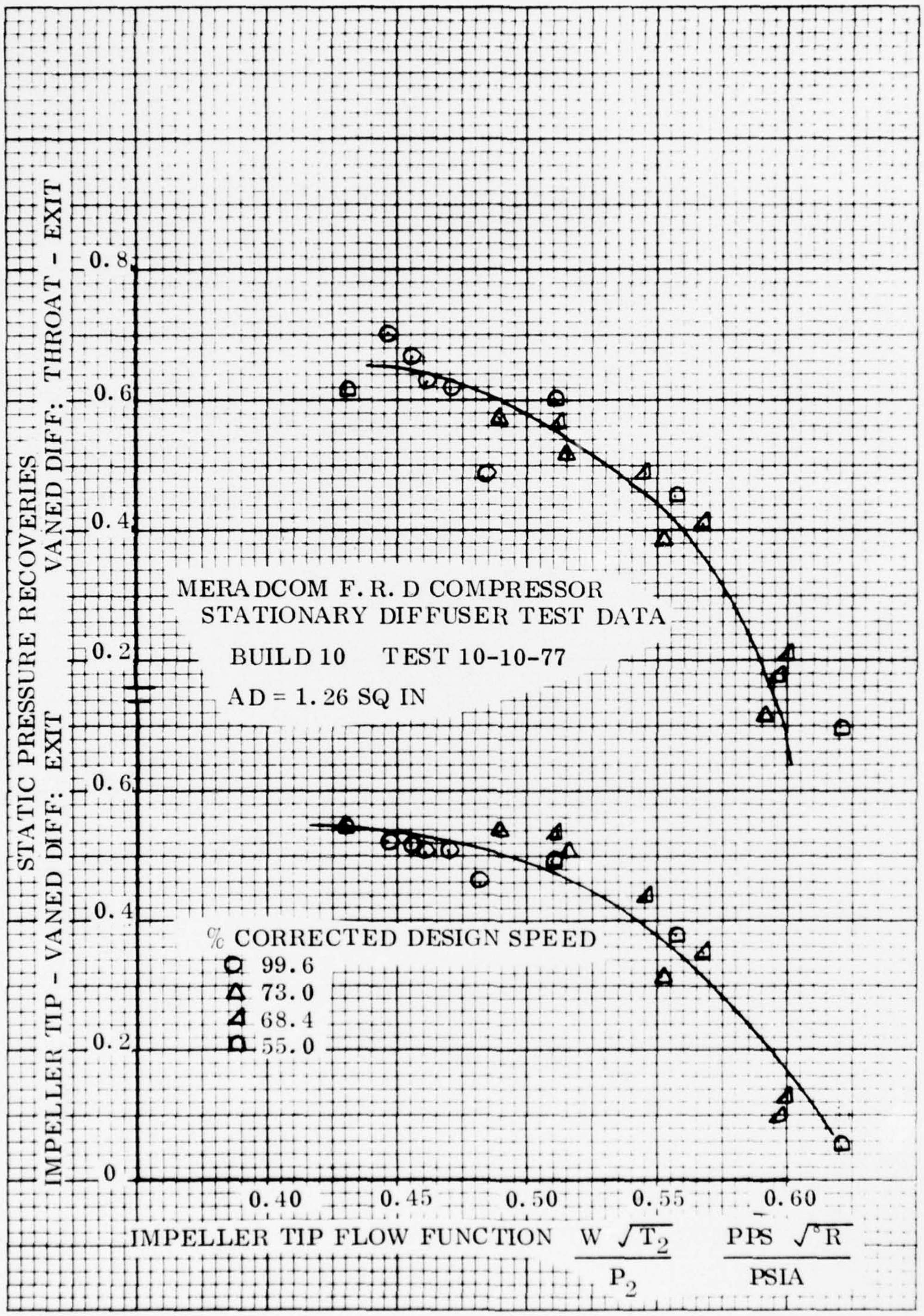

MERADCOM FREE ROTATING DIFFUSER
PERFORMANCE
BUILD 10
6 STRUTS
TEST 10-10-77
SPEED RATIO
STATIC RECOVERY TOTAL PRESS LOSS ΔP
P2 - p2
% CORRECTED DESIGN SPEED
99.6
79.0
68.4
55.0
0.4
0.3
0.2
0.3
0.2
0.1
0.3
0.2
0.35
0.40
0.45
0.50
0.55
0.60
IMPELLER TIP FLOW FUNCTION W √T2 / P2 PPS √°R / PSIA

Figure 26



STATIC PRESSURE RECOVERIES
IMPELLER TIP - VANED DIFF: EXIT
VANED DIFF: THROAT - EXIT
0.8
0.6
0.4
0.2
0.6
0.4
0.2
0
0.40
0.45
0.50
0.55
0.60
IMPELLER TIP FLOW FUNCTION W √T2 / P2 PPS √°R / PSIA
MERADCOM F. R. D COMPRESSOR
STATIONARY DIFFUSER TEST DATA
BUILD 10 TEST 10-10-77
AD = 1.26 SQ IN
% CORRECTED DESIGN SPEED
99.6
73.0
68.4
55.0

Figure 27

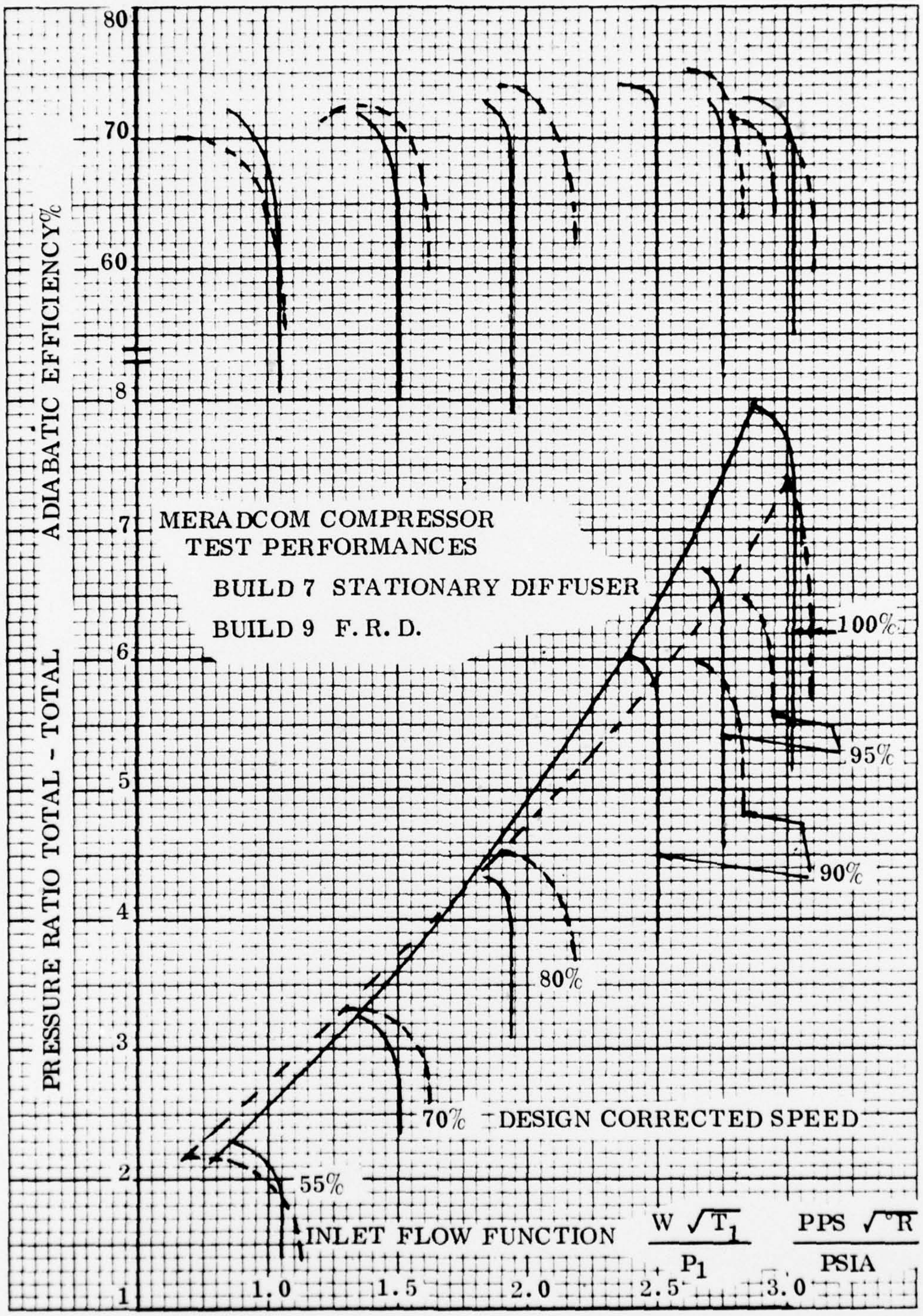

MERADCOM COMPRESSOR
TEST PERFORMANCES
BUILD 7 STATIONARY DIFFUSER
BUILD 9 F. R. D.
ADIABATIC EFFICIENCY%
PRESSURE RATIO TOTAL - TOTAL
80
70
60
8
7
6
5
4
3
2
1
100%
95%
90%
80%
70%
DESIGN CORRECTED SPEED
55%
INLET FLOW FUNCTION
W √T1 / P1
PPS √°R / PSIA
1.0
1.5
2.0
2.5
3.0

Figure 28

APPENDIX A

REDUCED TEST DATA FOR BUILDS 7, 8, 9, and 10

09/15/76 11.26.32

MERDC COMPRESSOR BUILD 7 STATIONARY DIFFUSER 09-09-76 P-440

REDUCED DATA

DATA POINT		1	2	3	4	5	6	7	8	9	10
N	RPM	34046.	34114.	34114.	34114.	34080.	43414.	43414.	43414.	43393.	43457.
W	PPS	0.6764	0.6765	0.6638	0.6025	0.5508	0.9726	0.9719	0.9721	0.9677	0.9273
DEL P ORIF	PSI	-0.05	-0.05	-0.05	-0.04	-0.04	-0.11	-0.11	-0.11	-0.11	-0.10
BAROMETER	PSIA	14.73	14.73	14.73	14.73	14.73	14.73	14.73	14.73	14.73	14.73
ORIFICE TEMP	DEG R	516.67	516.57	516.27	516.37	515.27	516.47	517.17	516.97	516.97	516.87

FIRST STAGE DATA

T1	DEG F	59.23	60.13	59.77	61.23	59.77	60.50	62.53	61.20	61.23	60.70
P STA 0	PSIA	20.96	20.99	21.00	20.96	21.02	25.77	25.77	25.74	25.74	25.84
P TOT 1	PSIA	14.70	14.69	14.69	14.69	14.68	14.65	14.65	14.66	14.68	14.67
P STA 2	PSIA	23.82	23.92	23.95	23.82	23.90	31.02	31.03	31.00	31.07	31.21
P STA 3	PSIA	22.87	22.92	23.44	25.53	27.06	33.72	33.72	33.69	33.69	33.84
P TOT THROAT	PSIA	19.55	25.22	30.08	31.46	31.99	25.57	32.45	38.25	43.46	45.78
P STA 4	PSIA	18.02	24.17	29.62	31.04	32.63	22.07	30.96	37.06	42.11	44.95
P TOT EXIT	PSIA	18.54	24.33	29.85	31.28	31.84	22.87	31.35	37.28	42.13	45.43
TE	DEG F	234.80	237.23	239.20	241.10	244.53	334.90	344.33	345.43	346.30	346.07
MOTOR CURRENT	AMPS	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
MTR POTENTIAL	VOLT	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

09/15/76 11.26.32

MERDC COMPRESSOR BUILD 7 STATIONARY DIFFUSER 09-09-76 P-440

REDUCED DATA

DATA POINT		11	13	14	15	16	17	18	19	21	22
N	RPM	43466.	49671.	49671.	49457.	49543.	43586.	55993.	56143.	56177.	56143.
W	PPS	0.8701	1.2379	1.2388	1.2393	1.2248	0.8874	1.6020	1.5834	1.5900	1.5956
DEL P ORIF	PSI	-0.09	-0.18	-0.18	-0.18	-0.18	-0.09	-0.31	-0.30	-0.30	-0.30
BAROMETER	PSIA	14.73	14.73	14.73	14.73	14.73	14.73	14.73	14.73	14.73	14.73
ORIFICE TEMP	DEG R	517.07	521.87	521.07	517.87	518.57	519.57	520.27	522.27	523.07	522.77

FIRST STAGE DATA

T1	DEG F	61.77	64.67	62.97	60.40	62.90	63.07	64.43	65.50	66.47	66.17
P STA 0	PSIA	25.71	30.32	30.48	30.19	30.34	25.67	36.22	36.35	36.29	36.32
P TOT 1	PSIA	14.65	14.66	14.65	14.65	14.64	14.69	14.59	14.59	14.55	14.50
P STA 2	PSIA	31.10	38.30	38.42	38.10	38.23	31.17	47.49	47.77	47.60	47.70
P STA 3	PSIA	37.96	45.04	45.24	44.62	45.43	34.84	61.46	61.72	61.58	61.43
P TOT THROAT	PSIA	47.89	41.03	48.94	58.30	62.45	46.70	44.66	56.34	76.09	81.78
P STA 4	PSIA	47.25	38.35	47.58	56.40	61.44	45.78	36.35	52.28	73.25	79.50
P TOT EXIT	PSIA	47.51	39.23	48.21	56.55	61.99	46.39	38.44	53.38	73.49	79.85
TE	DEG F	351.67	426.33	428.97	424.17	429.83	353.23	509.53	528.40	526.60	531.73
MOTOR CURRENT	AMPS	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
MTR POTENTIAL	VOLT	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

09/15/76 11.26.32

MERDC COMPRESSOR BUILD 7 STATIONARY DIFFUSER 09-09-76 P-440

REDUCED DATA

DATA POINT		23	24	25	26	27	30	31	32	33	34
N	RPM	56100.	56143.	56078.	59800.	58714.	58714.	58714.	58800.	62057.	62066.
W	PPS	1.5802	1.5332	1.4850	1.7869	1.6068	1.7576	1.7541	1.7380	1.9166	1.9150
DEL P ORIF	PSI	-0.30	-0.28	-0.26	-0.38	-0.31	-0.37	-0.37	-0.36	-0.44	-0.44
BAROMETER	PSIA	14.73	14.73	14.73	14.73	14.73	14.73	14.73	14.73	14.73	14.73
ORIFICE TEMP	DEG R	522.67	522.37	521.77	519.37	517.17	516.27	516.97	518.17	519.07	518.77

FIRST STAGE DATA

TI	DEG F	66.43	65.37	64.83	61.03	58.07	60.10	60.57	63.23	64.40	63.93
P STA 0	PSIA	36.20	36.89	36.42	38.84	40.39	38.73	38.88	39.02	41.32	41.41
P TOT 1	PSIA	14.50	14.53	14.61	14.55	14.61	14.57	14.57	14.57	14.51	14.52
P STA 2	PSIA	47.52	47.67	47.75	52.11	53.43	51.86	52.02	52.11	56.19	56.31
P STA 3	PSIA	61.39	65.38	62.36	70.22	67.81	69.86	69.93	69.83	79.21	79.39
P TOT THROAT	PSIA	84.88	87.95	86.62	63.46	71.11	69.63	81.52	94.99	80.05	93.52
P STA 4	PSIA	83.31	86.37	84.94	59.31	68.58	66.41	78.53	92.83	75.73	89.98
P TOT EXIT	PSIA	84.06	87.2[illegible]	85.81	60.44	70.50	67.93	79.25	93.28	79.02	91.01
TE	DEG F	533.03	536.50	532.43	565.93	574.67	560.77	569.77	576.40	629.07	634.17
MOTOR CURRENT	AMPS	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
MTR POTENTIAL	VOLT	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

09/15/76 11.26.32

MERDC COMPRESSOR BUILD 7 STATIONARY DIFFUSER 09-09-76 P-440

REDUCED DATA

DATA POINT		35	36	37	38	39
N	RPM	62143.	62528.	62571.	62571.	62571.
W	PPS	1.9158	1.8973	1.8214	1.8586	1.7744
DEL P ORIF	PSI	-0.44	-0.44	-0.40	-0.42	-0.38
BAROMETER	PSIA	14.73	14.73	14.73	14.73	14.73
ORIFICE TEMP	DEG R	518.37	523.87	529.37	526.47	525.37

FIRST STAGE DATA

T1	DEG F	64.87	70.57	71.83	72.33	71.83
P STA 0	PSIA	41.36	41.82	43.05	42.38	43.05
P TOT 1	PSIA	14.51	14.53	14.54	14.55	14.54
P STA 2	PSIA	56.24	56.81	58.15	57.21	58.15
P STA 3	PSIA	78.85	79.60	82.62	80.32	82.62
P TOT THROAT	PSIA	101.16	110.09	115.14	112.41	118.73
P STA 4	PSIA	97.83	108.08	113.39	110.59	113.39
P TOT EXIT	PSIA	98.46	108.96	114.46	111.59	116.73
TE	DEG F	637.80	650.67	654.73	653.33	654.73
MOTOR CURRENT	AMPS	1.00	1.00	1.00	1.00	1.00
MTR POTENTIAL	VOLT	1.00	1.00	1.00	1.00	1.00

REDUCED DATA

DATA POINT		1	2	3	4	5	6	7	8	9	10
N	RPM	34457.	34436.	34586.	34671.	43800.	43929.	43886.	43929.	43843.	50121.
W	PPS	0.7027	0.6695	0.5333	0.4185	0.9997	0.9744	0.8711	0.8495	0.7798	1.3152
PCD ORIFICE	PSIA	-0.31	-0.28	-0.17	-0.11	-0.63	-0.60	-0.47	-0.45	-0.38	-1.13
BAROMETER	PSIA	14.74	14.74	14.74	14.74	14.74	14.74	14.74	14.74	14.74	14.74
ORIFICE TEMP	DEG R	525.47	523.47	520.87	523.17	520.57	523.07	523.07	521.97	521.37	518.87

ROTATING DIFFUSER

SPEED COUNT		10500.0	10815.0	12090.0	12885.0	14940.0	15465.0	16305.0	16905.0	16935.0	17955.0
LOAD RATIO		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DIFF.SPEED	RPM	10500.	10815.	12090.	12885.	14940.	15465.	16305.	16905.	16935.	17955.
SPEED RATIO		0.3047	0.3141	0.3496	0.3716	0.3411	0.3520	0.3715	0.3848	0.3863	0.3582
HP BRAKE		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

STAGE DATA

T1	DEG F	72.03	71.13	68.60	74.60	67.93	72.43	70.27	70.43	72.60	68.97
P TOT 1	PSIA	14.50	14.53	14.60	14.64	14.24	14.27	14.37	14.37	14.46	13.88
P STA 2	PSIA	23.33	23.36	23.67	23.65	30.53	30.97	31.56	31.50	31.27	36.86
P STA 2-3	PSIA	27.47	27.54	27.77	27.74	38.33	38.57	38.96	38.96	38.66	48.18
P STA 3	PSIA	21.76	22.83	26.41	27.87	32.49	34.31	37.59	38.89	38.63	42.67
P STA 4	PSIA	20.03	24.96	30.48	31.08	33.65	41.90	45.37	46.40	45.76	46.91
P TOT E	PSIA	21.12	25.76	30.48	31.10	34.74	42.35	45.33	46.31	45.71	48.09
TE	DEG F	243.07	246.13	252.20	261.70	348.37	360.97	365.57	370.20	370.00	439.90

REDU( )ATA

( )A POINT		11	12	13	14	15	16
N	RPM	50143.	50143.	50143.	55842.	55971.	56186.
W	PPS	1.2763	1.2324	1.1630	1.6255	1.6190	1.5736
PCD ORIFICE	PSIA	-1.06	-0.98	-0.86	-1.82	-1.80	-1.70
BAROMETER	PSIA	14.74	14.74	14.74	14.71	14.71	14.71
ORIFICE TEMP	DEG R	519.67	518.57	518.57	515.07	515.17	518.47

ROTATING DIFFUSER

SPEED COUNT		18315.0	18885.0	19380.0	20415.0	20836.0	21465.0
LOAD RATIO		0.0	0.0	0.0	0.0	0.0	0.0
DIFF.SPEED	RPM	18315.	18885.	19380.	20415.	20836.	21465.
SPEED RATIO		0.3653	0.3766	0.3865	0.3656	0.3723	0.3820
HP BRAKE		0.0	0.0	0.0	0.0	0.0	0.0

STAGE DATA

T1	DEG F	69.63	69.17	69.73	62.23	61.90	68.87
P TOT 1	PSIA	13.92	13.98	14.05	13.16	13.16	13.32
P STA 2	PSIA	37.32	38.13	39.08	39.80	40.48	41.79
P STA 2-3	PSIA	48.59	49.35	50.22	57.30	58.71	60.04
P STA 3	PSIA	43.17	47.08	49.80	52.68	53.35	57.71
P STA 4	PSIA	54.99	59.10	61.58	58.85	68.36	74.46
P TOT E	PSIA	55.26	59.18	61.46	59.91	68.01	74.79
TE	DEG F	445.70	449.73	456.57	512.50	521.33	532.23

BEST AVAILABLE COPY

BEST AVAILABLE COPY

REDUCE 'A

DA.. POINT		17	18	19	20	21	22	23	923	24
N	RPM	58414.	58714.	58971.	61971.	62143.	62271.	62250.	62250.	56057.
W	PPS	1.6847	1.6810	1.6691	1.7319	1.7287	1.7288	1.7159	1.6931	1.5964
PCD ORIFICE	PSIA	-1.96	-1.96	-1.94	-2.13	-2.12	-2.12	-2.09	-2.02	-1.76
BAROMETER	PSIA	14.65	14.65	14.65	14.65	14.65	14.65	14.65	14.65	14.65
ORIFICE TEMP	DEG R	508.67	510.87	513.07	514.87	515.37	515.97	514.37	516.37	516.57
ROTATING DIFFUSER										
SPEED COUNT		21555.0	22065.0	22455.0	23205.0	23550.0	24015.0	24300.0	24300.0	28877.0
LOAD RATIO		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DIFF.SPEED	RPM	21555.	22065.	22455.	23205.	23550.	24015.	24300.	24300.	28877.
SPEED RATIO		0.3690	0.3738	0.3808	0.3744	0.3790	0.3857	0.3904	0.3904	0.5151
HP BRAKE		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
STAGE DATA										
T1	DEG F	56.40	58.93	61.87	63.13	64.07	65.00	65.50	65.50	65.20
P TOT 1	PSIA	13.08	13.07	13.16	12.84	12.98	12.95	12.95	12.96	13.29
P STA 2	PSIA	40.69	41.57	41.73	40.19	41.12	42.91	44.59	44.59	39.47
P STA 2-3	PSIA	60.29	61.32	63.49	61.78	63.03	65.64	67.91	67.91	57.04
P STA 3	PSIA	53.47	57.00	59.91	58.89	59.98	63.56	67.46	69.75	52.47
P STA 4	PSIA	62.26	71.90	78.38	65.46	75.65	83.49	87.77	91.15	62.68
P TOT E	PSIA	63.54	72.11	78.44	66.67	75.81	83.45	87.45	90.65	63.28
TE	DEG F	552.90	564.57	573.63	624.57	630.47	636.23	638.93	638.93	525.63

F.R.D. BUILD 10 10-10-77 P-453 10/19/77 16.59.05

REDUCED DATA

DATA POINT		7	8	9	10	11	13	14	19	16	17
N	RPM	34400.	34714.	34900.	35700.	35420.	47200.	48600.	49300.	49400.	49700.
W	PPS	0.8134	0.8135	0.7334	0.5753	0.6743	1.4528	1.4526	1.4082	1.3489	1.2871
PCD ORIFICE	PSIA	-0.08	-0.08	-0.06	-0.04	-0.05	-0.25	-0.25	-0.24	-0.22	-0.20
BAROMETER	PSIA	14.73	14.73	14.73	14.73	14.73	14.73	14.73	14.73	14.73	14.73
ORIFICE TEMP	DEG R	538.27	538.07	538.57	539.47	539.47	530.87	530.97	532.37	532.67	532.67
ROTATING DIFFUSER											
SPEED COUNT		8920.0	8940.0	9450.0	10005.0	9810.0	14310.0	14985.0	15000.0	15180.0	15450.0
LOAD RATIO		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DIFF.SPEED	RPM	8920.	8940.	9450.	10005.	9810.	14310.	14985.	15000.	15180.	15450.
SPEED RATIO		0.2593	0.2575	0.2708	0.2803	0.2770	0.3032	0.3083	0.3043	0.3073	0.3109
HP BRAKE		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
STAGE DATA											
T1	DEG F	81.30	82.03	84.10	84.90	84.60	72.23	73.50	75.07	74.87	74.90
P TOT 1	PSIA	14.70	14.70	14.70	14.71	14.71	14.62	14.63	14.63	14.65	14.65
P STA 2	PSIA	23.10	23.11	23.27	23.55	23.50	35.15	36.02	36.94	37.65	37.88
P STA 2-3	PSIA	27.81	27.86	27.92	28.19	28.26	48.23	48.32	49.35	50.13	50.30
P STA 3	PSIA	22.33	22.28	24.83	28.35	26.78	42.76	42.82	43.39	46.48	48.36
P STA 4	PSIA	20.25	23.74	28.77	31.43	30.78	31.27	40.35	51.93	58.50	60.23
P TOT E	PSIA	21.11	24.29	28.73	30.95	30.43	34.25	41.28	51.78	57.94	59.35
TE	DEG F	250.50	256.33	262.53	278.00	268.43	392.93	419.27	436.73	443.20	449.73

REDUCED DATA											
DATA POINT		18	19	20	21	22	23	24	25	26	27
N	RPM	41300.	42600.	43000.	42800.	42800.	42800.	42800.	53600.	54700.	55000.
W	PPS	1.1177	1.1174	1.0599	1.0001	0.9137	1.0984	1.0403	1.7170	1.6789	1.6810
PCD ORIFICE	PSIA	-0.15	-0.15	-0.13	-0.12	-0.10	-0.14	-0.13	-0.36	-0.34	-0.34
BAROMETER	PSIA	14.73	14.73	14.73	14.73	14.73	14.73	14.73	14.73	14.73	14.73
ORIFICE TEMP	DEG R	531.67	531.97	532.77	532.47	532.37	532.37	532.67	532.37	534.17	532.87
ROTATING DIFFUSER											
SPEED COUNT		11970.0	12300.0	12285.0	12270.0	12405.0	12075.0	12315.0	17055.0	17205.0	17310.0
LOAD RATIO		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DIFF.SPEED	RPM	11970.	12300.	12285.	12270.	12405.	12075.	12315.	17055.	17205.	17310.
SPEED RATIO		0.2898	0.2887	0.2857	0.2867	0.2898	0.2821	0.2877	0.3182	0.3145	0.3147
HP BRAKE		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
STAGE DATA											
T1	DEG F	74.70	75.20	75.07	75.20	76.03	74.73	74.67	74.70	75.00	75.53
P TOT 1	PSIA	14.65	14.68	14.68	14.67	14.69	14.67	14.69	14.59	14.59	14.59
P STA 2	PSIA	29.23	29.61	29.54	29.10	28.76	29.43	30.16	41.48	43.25	44.31
P STA 2-3	PSIA	37.35	37.89	37.54	36.77	36.31	37.45	38.34	57.36	59.67	60.97
P STA 3	PSIA	31.66	31.98	32.65	33.24	34.10	31.41	32.70	52.17	54.06	55.04
P STA 4	PSIA	24.68	34.70	39.23	40.32	41.08	33.38	38.40	41.12	56.80	67.43
P TOT E	PSIA	26.57	35.17	39.15	40.05	40.63	33.95	38.47	43.44	57.68	66.91
TE	DEG F	315.13	339.93	346.03	345.60	345.10	340.43	348.67	483.70	506.17	517.73

BEST AVAILABLE COPY

REDUCED DATA						
DATA POINT		28	29	30	31	32
N	RPM	56000.	56000.	56500.	56500.	43300.
W	PPS	1.6561	1.8269	1.8039	1.7565	1.0959
PCD ORIFICE	PSIA	-0.33	-0.41	-0.40	-0.38	-0.14
BAROMETER	PSIA	14.73	14.73	14.73	14.73	14.73
ORIFICE TEMP	DEG R	533.47	533.57	534.27	536.17	534.87
ROTATING DIFFUSER						
SPEED COUNT		17310.0	17955.0	17925.0	17955.0	12000.0
LOAD RATIO		0.0	0.0	0.0	0.0	0.0
DIFF.SPEED	RPM	17310.	17955.	17925.	17955.	12000.
SPEED RATIO		0.3091	0.3206	0.3173	0.3178	0.2771
HP BRAKE		0.0	0.0	0.0	0.0	0.0
STAGE DATA						
T1	DEG F	76.20	77.60	76.97	77.20	77.57
P TOT 1	PSIA	14.59	14.56	14.56	14.56	14.67
P STA 2	PSIA	45.11	43.80	45.58	46.50	27.20
P STA 2-3	PSIA	61.95	61.28	63.85	65.00	34.36
P STA 3	PSIA	55.89	56.16	58.42	59.29	28.72
P STA 4	PSIA	72.04	45.17	63.92	73.20	25.07
P TOT E	PSIA	71.04	47.00	64.32	72.49	25.93
TE	DEG F	526.20	530.30	545.60	553.67	319.07

F.R.D. BUILD 10 10-13-77 P-453 10/19/77 18.33.19

REDUCED DATA

DATA POINT		33	34	35	36	37	38	39	40	41	42
N	RPM	57100.	58700.	61100.	61400.	61800.	62000.	62500.	62600.	62700.	62700.
W	PPS	1.6351	1.6081	1.6698	1.6528	1.6560	1.6475	1.6541	1.6466	1.6457	1.6367
PCD ORIFICE	PSIA	-1.88	-1.82	-2.01	-1.97	-1.96	-1.94	-1.96	-1.94	-1.95	-1.92
BAROMETER	PSIA	14.72	14.72	14.72	14.72	14.72	14.72	14.72	14.72	14.72	14.72
ORIFICE TEMP	DEG R	524.37	527.47	531.47	533.67	529.37	530.27	530.57	530.87	533.77	532.67

ROTATING DIFFUSER

SPEED COUNT		18480.0	18660.0	19695.0	19605.0	19650.0	19620.0	19875.0	19830.0	19875.0	19815.0
LOAD RATIO		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DIFF.SPEED	RPM	18480.	18660.	19695.	19605.	19650.	19620.	19875.	19830.	19875.	19815.
SPEED RATIO		0.3236	0.3179	0.3223	0.3193	0.3180	0.3165	0.3180	0.3168	0.3170	0.3160
HP BRAKE		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

STAGE DATA

T1	DEG F	70.73	72.93	72.47	74.30	74.30	75.37	75.47	75.30	75.23	74.27
P TOT 1	PSIA	13.30	13.32	13.18	13.18	13.24	13.25	13.23	13.24	13.23	13.28
P STA 2	PSIA	41.93	43.64	44.34	45.31	45.99	47.02	47.53	48.05	48.66	49.46
P STA 2-3	PSIA	49.74	61.97	64.01	65.16	65.91	67.20	68.24	68.69	69.65	70.54
P STA 3	PSIA	55.30	57.19	60.25	61.13	61.57	62.67	63.93	64.12	65.38	66.57
P STA 4	PSIA	42.27	62.30	65.99	72.68	76.59	80.76	83.17	83.71	85.74	87.50
P TOT E	PSIA	44.81	62.94	66.64	72.48	75.87	79.38	81.79	82.36	84.51	86.44
TE	DEG F	546.73	576.03	617.43	625.53	633.00	636.67	644.83	647.93	650.73	649.17

BEST AVAILABLE COPY

REDUCED DATA		
DATA POINT		44
N	RPM	63100.
W	PPS	1.5992
PCD ORIFICE	PSIA	-1.81
BAROMETER	PSIA	14.72
ORIFICE TEMP	DEG R	530.87
ROTATING DIFFUSER		
SPEED COUNT		19920.0
LOAD RATIO		0.0
DIFF.SPEED	RPM	19920.
SPEED RATIO		0.3157
HP BRAKE		0.0
STAGE DATA		
T1	DEG F	74.13
P TOT 1	PSIA	13.32
P STA 2	PSIA	50.77
P STA 2-3	PSIA	72.22
P STA 3	PSIA	69.47
P STA 4	PSIA	92.15
P TOT E	PSIA	91.02
TE	DEG F	664.67